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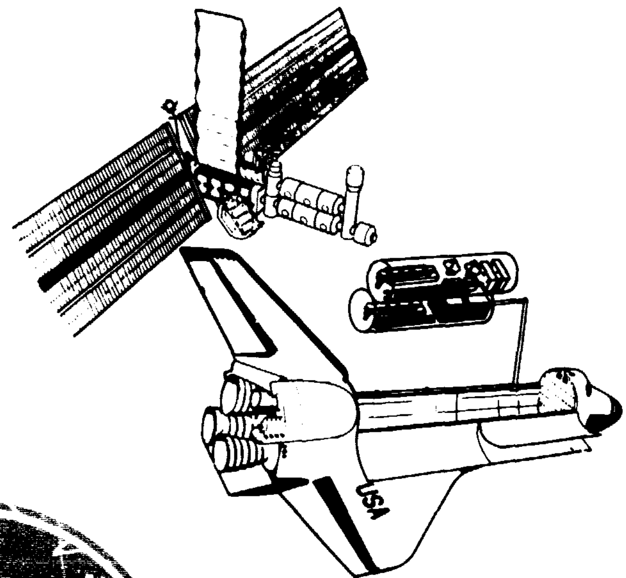
TRW Space & Technology Group

DR-4

Definition of Satellite Servicing Technology Development Missions for Early Space Stations

Volume I Executive Summary

31 May 1983



Prepared for
NASA GEORGE C. MARSHALL SPACE FLIGHT CENTER
Under
Contract No. NAS8-35081
in Accordance with
Data Procurement Document No. 628

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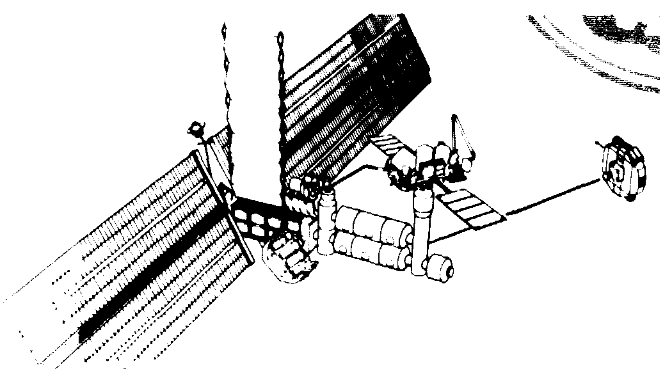

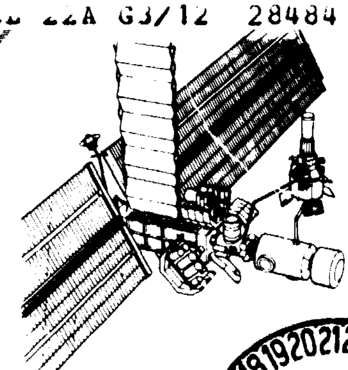

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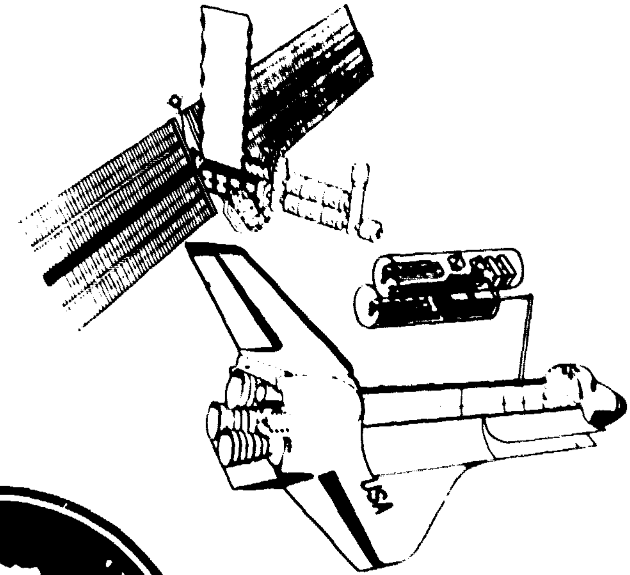

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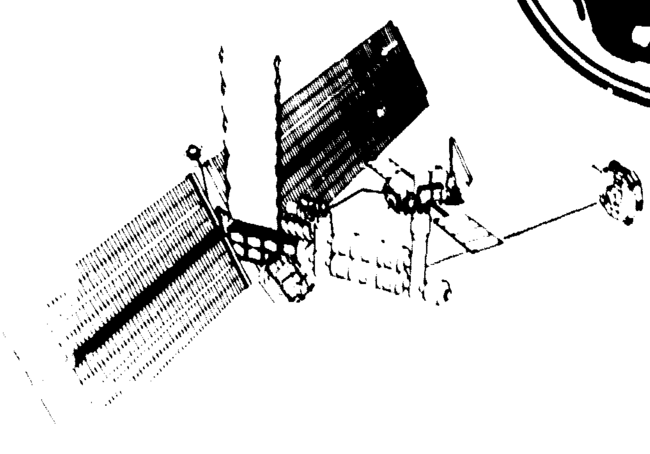

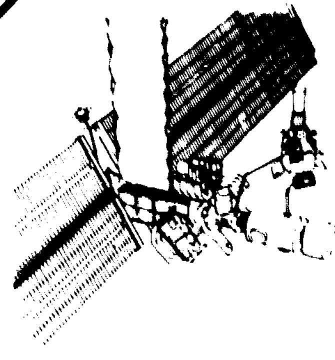

PREFACE

This study, performed by the TRW Space and Technology Group under Contract NAS8-35081 for the NASA Marshall Space Flight Center, Alabama addressed the definition of candidate satellite servicing technology development missions that could benefit from the use of an early, 1991, manned space station.

The study started on 1 October 1982. Part I was completed on 31 May 1983. Three major tasks were addressed: Mission Requirements, Mission Definition of Selected Satellite Servicing Technology Development Missions, and Programmatic Analysis of the selected missions. It was found that almost all scientific, applications, and commercial missions planned for in the 1985-2000 time period could benefit from some aspect of servicing on-orbit. The early space station was deemed vital as a necessary step in the establishment of on-orbit satellite servicing as an on-going, effective, national capability in the last decade of the century.

Part II, an extension to the work of Part I, will start about 1 June 1983 and continue for 18 months.

The study final report for Part I consists of three volumes generated in accordance with DR-4 and 5 of the contract data procurement Document No. 628:

- Volume I - Executive Summary
- Volume II - Technical Report
- Volume III - Environmental Analysis

This is Volume I - Executive Summary.

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LIST OF ACRONYMS

AXAF	Advanced X-Ray Astrophysics Facility
EVA	Extra-Vehicular Activity
GEO	Geosynchronous Earth Orbit
GRO	Gamma Ray Observatory
HUD	Heads-Up Display
IRAD	Internal Research and Development
IVA	Inter-Vehicular Activity
LDEF	Long Duration Exposure Facility
LEO	Low Earth Orbit
MEC	Materials Experiment Carrier
MMS	Multi-Mission Spacecraft
MMU	Manned Maneuvering Unit
MPP	Materials Processing Platform
MSS	Manned Space Station
ORU	Orbital Replacement Unit
OSTS	Office of Space Transportation System
OTV	Orbtial Transfer Vehicle
P/L	Payload
PP	Processing Platform (Materials)
RMS	Remote Manipulator System
S/C	Spacecraft
SS	Space Station (Manned)
SSUM	Satellite Servicing User's Model
ST	Space Telescope
STS	Space Transportation System
TDE	Technology Development Element
TMS	Teleoperator Maneuvering System

1.0 INTRODUCTION

Projections of candidate space missions through the year 2000 have identified several key operations which will require a manned presence in space. One such operation is the periodic servicing of free-flying spacecraft accessible from a manned space station in low earth orbit.

This study, conducted by TRW for the NASA Marshall Space Flight Center from 1 October 1982 through 31 May 1983, defined the initial requirements for selected satellite servicing technology development missions (TDMs) which could benefit from the support of a manned space station. Although the requirements, both technical and programmatic, were time phased, they were aimed primarily at the early (FY 1991) space station. With these initial requirements, five TDMs were generated which are base-line to establishing a national on-orbit satellite servicing capability.

The conclusion was reached that on-orbit satellite servicing will support a wide range of NASA, DoD, and commercial missions, and that the broad, yet special, nature of this support portends economic and operational benefits to the users.

Our goal was to identify those technologies that enable a high leverage on satellite servicing development at affordable costs. Advantage was taken of the opportunity to suggest TDM precursor experiments - both earth-based and conducted on 1985 to 1990 Space Shuttle flights. Thus the time frame of implementation, in this study, is from 1985 through the year 2000. A road map was laid out over this span showing a satellite servicing evolutionary and flight demonstration technology plan.

1.1 TDM DEFINITION

A Technology Development Mission is an experimental project aimed at advancement of an operational technique or a hardware item for the benefit of satellite servicing activities. It receives support from the space station. It can have a value for science, applications, commercial uses or national security. It can influence the initial space station design and operational modes. A given TDM may be part of a total technology development (related to other TDMs) with precursor tests. Each TDM, to be cost effective, must consider

and quantify benefits versus cost. One way to avoid unrealistic costs is to plan TDMs which are not dead-ended i.e., have a residual value.

1.2 FOLLOW-ON TO THE CURRENT WORK

The current study, reported on herein, is Part I of a two part effort sponsored by NASA/MSFC. Part II of this study will start in early June 1983 and continue for 18 months. The follow-on work will build upon and expand the results of Part I and provide further detailing and definition of space station satellite servicing operations. The objectives of the six task follow-on work statement are the same as the objectives of Part I except that more emphasis will be placed on the 1) impact of TDMs on the space station architecture and operations and 2) assessment of satellite servicing potential to space industrial operations.

Thus NASA will, at the conclusion of the second phase of this study, be in a position to plan for the next steps on the path to making satellite servicing a routine, cost effective, safe, and dependable function of spaceflight in the 1990s and beyond.

2.0 STUDY OBJECTIVES

The three general satellite servicing mission/operations studied were, in summary: modification to the space station itself to form both the initial and later configuration evolution; repair, refueling, and/or upgrading of satellites; and assembly on-orbit of spacecraft whose final configuration exceeds the inidividual STS payload capability. There have been studies performed on these general topics in recent years and they provided a valuable source of information for this study. However, none in themselves fully considered the complete space station system, particularly its evolution over the mission time span, say from 1990 to 2000. These studies were more concerned with an individual vehicle/mission aspect such as TMS, OTV, Power Module, or Platform Structure in a configuration that did not change with time.

This study dealt with the feasibility and requirements for servicing and maintaining a free-flying satellite from a manned space facility. Although the servicing would be over the lifespan of the facility, special emphasis was

placed on the early time periods - 1990 to 1995.

The objectives, then, of this study were to:

1. Define the testbed role of an early (1990) manned space station in the context of a satellite servicing evolutionary development and flight demonstration technology plan which results in a satellite servicing operational capability by the late 1990s.

2. Conceptually define a satellite technology development mission (a set of missions) to be performed on an early manned space station.

3.0 STUDY GUIDELINES

The basic top-level guidelines shown below were used in the performance of this study.

Secondary ground rules were adhered to in the conduct of the study. All were found to be useful as the work progressed. Sometimes two or more were applied to the outcome of a single TDM.

MSFC SPECIFIED

- Make maximum use of prior and current projects and studies.
- The space shuttle is the earth launch vehicle. (User's Handbook providing guidelines.)
- An early space station is operational in low earth orbit in 1990.
- A TMS is available to support on-orbit operations.

TRW ADDED

- Consider use of MSFC's neutral buoyancy facility for certain ground tests.
- Satellite servicing operations can occur at the space station as well as remote from the space station.
- Specific costing ground rules will be developed by TRW prior to the start of Task 3 (Programmatic Analysis).

4.0 STUDY APPROACH AND MILESTONES

The Satellite Servicing TDMs for Early Space Stations Study, Part I, was performed against three major tasks whose logic network and work flow are shown in Figure 4-1. The study was highly coupled with the TRW Space Station Needs, Attributes and Architectural Options Study conducted for NASA (Contract NASW-3681). Therefore, much of the work and many results of the space station study were applied directly to this Satellite Servicing TDM study.

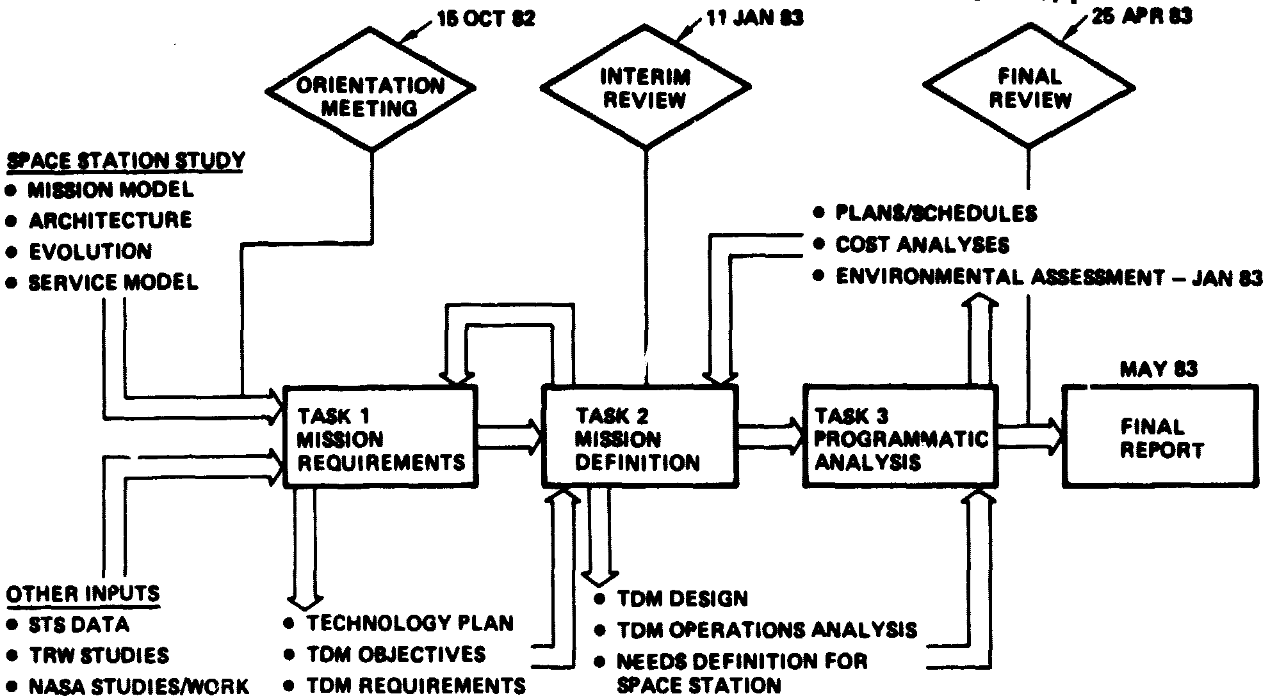

Figure 4-1. Summary of Study Task Flow and Schedule

The three major tasks, Figure 4-1, each took the outputs of prior tasks as principal input. On the flow, note the strong interaction between Task 2 (Mission Definition) and Task 3 (Programmatics Analysis) in the TDM definition trade studies.

4.1 RELATED ACTIVITIES

An attempt was made to broaden the inputs to study results. Consequently many organizations were contacted for satellite servicing technology ideas and suggestions. Timely source information was obtained from:

1. TRW space station study, mentioned above.
2. TRW spacecraft project offices.
3. NASA centers other than the sponsor center (MSFC).
4. NASA Headquarters, OSTS and and Space Station Task Force.
5. TRW 1982 and 1983 IRAD projects.
6. Three other NASA/MSFC parallel TDM study contractors:
   a) Boeing, Large Space Structures
   b) General Dynamics Convair, OTV Servicing
   c) Martin Marietta, Satellite Servicing
7. United States Companies

Ball Aerospace	Fairchild
Essex	Ford Aerospace

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General Electric	Honeywell
Goodyear	Hughes
Grumman	RCA
Hamilton Std.	Vought

8. International Companies (Europe and Canada)

Aeritalia	MATRA
Aerospatiale	MBB
British Aerospace	SAAB-Scania
ERNO	Spar Aerospace

4.2 EARLY SPACE STATION CONCEPT

Due to the complex interfaces between the space station and satellite services conducted at or near the station, it was necessary to have a conceptualized configuration of an early space station. Figure 4-2 therefore is an artist's rendering of the 1990 space station derived by TRW in our NASA Space Station Study. This initial space station would be manned by a crew of five after having been installed in a 28.5° inclination orbit by four shuttle orbiter flights.

The modular design includes a resources module which supplies utilities, three habitable modules, two airlock modules, a logistics module, a manipulator and a platform area for assembly or servicing of space systems including satellites. This configuration can grow by the addition of more modules. The solar arrays shown are sized to deliver 30 kW net power to the modules and the servicing platform.

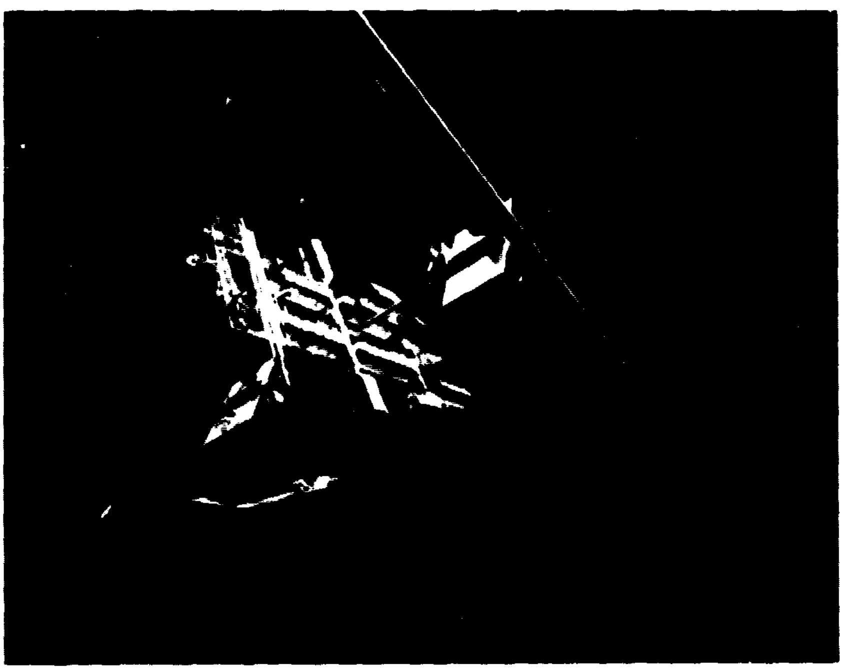

Figure 4-2. Early Space Station Concept

For expanded satellite assembly and/or servicing a hangar facility, fuel storage tanks, servicing logistics modules, crew training areas, special fixtures and a servicing command control center are envisioned as growth options of the station.

5.0 STUDY RESULTS

This section describes the results of the three study tasks. Key sequential steps were:

- Researched the state of current technology related to on-orbit satellite servicing.
- Determined the satellite servicing technology requirements for supporting satellite servicing needs in the space station era.
- Against a set of criteria that included economic, operational, technology, and user needs, generated a list of 26 satellite servicing TDMs that are candidates for hardware development implementation.
- By a numerical rating technique, selected and designed five TDMs, from the candidate 26, for the early space station to develop this servicing technology.
- Performed preliminary definition, scheduling and costing of the five selected TDMs.

5.1 TECHNOLOGY DEVELOPMENT MISSION REQUIREMENTS

This section summarizes results of study Task 1, definition of Technology Development Mission (TDM) requirements. In this task we reviewed the state of technology currently available for on-orbit satellite servicing and determined the needs for further evolution of this technology.

The capabilities for satellite servicing provided initially by the shuttle orbiter in the 1980s will have to be expanded to permit cost-effective utilization of the manned space station for the more demanding and large-scale satellite servicing operations projected for the 1990s. In Task 1 we determined the objectives and requirements of technology development missions that will support this evolution. This provided the point of departure for identifying three sets of candidate TDMs and, from these, selection of five specific missions for further study in Task 2. The candidate TDM missions were grouped in three principal categories of servicing objectives (see Figure 5.1-1) which involved modification and build-up of the space station itself (Category I); assembly, test and deployment of large satellites that are

to be placed in orbit for the first time (Category II); and retrieval, maintenance, refurbishment/repair and redeployment of other satellites that already will have operated in orbit for some length of time (Category III). The definition of TDM objectives and requirements in Task 1, and the selection of specifid TDMs and their mission scenarios in Task 2 were accomplished as interactive study efforts and involved some iteration.

5.1.1 TDM Objectives and Evolution

Requirements for servicing technology development derive from the large variety of satellite services that are to be provided by the manned space station. A total of about 50 servicing events per year, averaged over the 1990 to 2000 time period is projected on the basis of data from TRW's current Space Station Study.

Figure 5.1-2 shows a matrix of satellite servicing operation classes versus satellite types that will require servicing to illustrate the diversity of activities to be considered as well as the projected high incidence of servicing needs. It differentiates between servicing functions to be performed at the space station and those performed

CATEGORY I

SPACE STATION MODIFICATION AND BUILDUP

- **SPACE STATION GROWTH**
- **MODIFICATIONS FOR EXTENDED OPERATIONS**
- **MAINTENANCE AND REPAIR**

CATEGORY II

SPACECRAFT ASSEMBLY, TEST AND LAUNCH

- **SPACECRAFT TOO LARGE FOR SINGLE SHUTTLE LAUNCH**
- **ASSEMBLY TOO TIME CONSUMING TO BE DONE BY SHUTTLE**
- **NEED FOR LARGER CREWS, MORE EXTENSIVE SUPPORT EQUIPMENT**

CATEGORY III

SATELLITE SERVICING, REFURBISHMENT AND REPAIR

- **ROUTINE SERVICING**
- **REPAIR/REFURBISHMENT AS NECESSARY**
- **SPACE STATION SERVES AS DEPOT AND OPERATIONS BASE**

Figure 5.1-1. TDM Mission Categories and Objectives

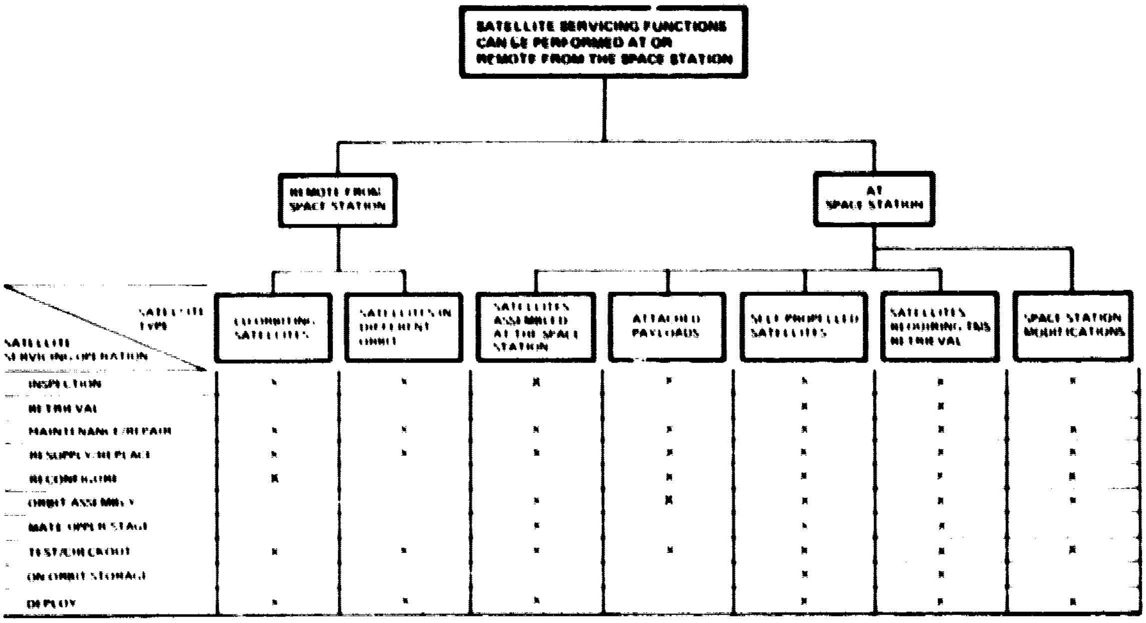

Figure 5.1-2. Satellite Servicing Operations

remotely ("in situ") at the orbital position of the satellite to be serviced. The latter tasks require the use of a TMS operating autonomously or under continuous control by command link from the space station. Both types of servicing needs will be addressed in the TDM examples selected for detailed study.

In the interest of cost effectiveness a combination between technology development/demonstration and operational mission support objectives was emphasized in defining the TDM candidates and also in selecting specific TDMs - one or two of each of the three TDM categories - for further detailed study. The ten technology development/demonstration objectives listed in Figure 5.1-3 are linked directly to specific operational objectives, all of which are priority concerns in satellite servicing to be performed by an early space station.

Transition from the servicing activities performed by the shuttle orbiter to those performed by a manned space station will be part of the required technology evolution. This transition involves:

a. Direct inheritance of servicing technology and procedures developed by the shuttle orbiter.

b. Development of advanced servicing technologies for space station's unique capabilities

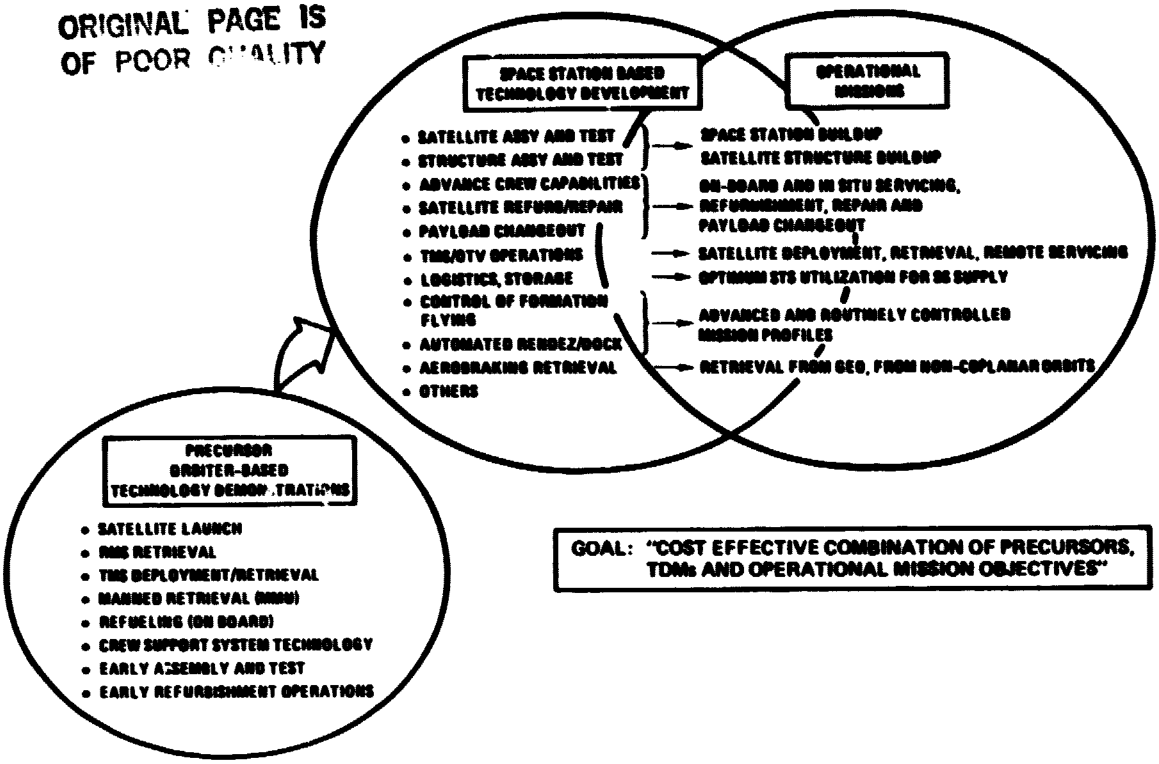

Figure 5.1-3. TDM Objectives and Evolution

However, servicing missions by the orbiter will continue to be important in the space station era because of the shuttle's inherently high mission profile flexibility. Thus, some aspects of SS servicing technology evolution will also feed back to enhance future orbiter servicing capabilities, e.g., utilization of OTVs, geostationary satellite retrieval, automated rendezvous and others.

5.1.2 TDM Technology Requirements

Figure 5.1-4 summarizes specific technology issues requiring further development in each of seven major areas of spacecraft, subsystem and mission engineering involved in satellite servicing. The items listed not only represent "top level" concerns, but indicate their diversity. Asterisks on many of the entries indicate that the technology in question has a significant impact on mission and/or crew safety and should therefore be given appropriate attention.

Two surveys - industry and internal TRW - with a subsequent qualitative assessment identified (a) dominant servicing technology requirements and (b) the most technologically demanding servicing activities.

1. STRUCTURES AND MECHANISMS	• MODULAR STRUCTURES • SELF-LATCHING FIXTURES • INFLATABLES*	• BEAM ALIGNMENT DURING CONSTRUCT • SHAPE CONTROL OF LARGE ANTENNAS
2. AUTOMATIC AND REMOTE CONTROL	• PRECISION ALIGNMENT OF PAYLOAD INSTRUMENTS • REMOTE MANIPULATION (TMS) UNDER VIDEO CONTROL* • AUTOMATED RENDEZVOUS/DOCKING*	• TMS DEXTERITY AND AUTOMATION* • MANIPULATION SAFETY* • ROBOTS/ARTIFICIAL INTELLIGENCE*
3. DATA HANDLING/ MANAGEMENT	• VIDEO DATA COMPRESSION • DIAGNOSTIC ROUTINES	• DECISION MAKING LOGIC • AUTONOMOUS OPERATIONS*
4. PROPULSION AND MANEUVER MODES	• TMS/ADVANCED TMS • OTV EVOLUTION, MANNED OTV*	• REFUELING (HANDS-ON OR REMOTELY CONTROLLED)*
5. SPACECRAFT DESIGN FOR SERVICING	• ORU STANDARDIZATION • INTERFACE STANDARDIZATION	• CREW ACCESS* • TMS ACCESS • SATELLITE SAFING FOR ACCESS*
6. CREW SUPPORT EQUIP AND CREW PROCEDURES	• MANIPULATION AIDS* • VISUAL NAV AIDS (MMU)* • CREW TRAINING EVOLUTION/FACILITIES*	• MOBILITY AIDS* • INFLATABLE WORK STATION (SUPER SUIT)*
7. ORBIT MECHANICS	• ZERO-VELOCITY RENDEZVOUS MODE* • FORMATION FLYING AND PROXIMITY OPS	• AEROBRAKING* (GEO SAT RETRIEVAL) • AEROBRAKING* (NON-COPLANAR SATELLITE TRANSFER)

*PRINCIPAL AREAS INVOLVING MISSION/CREW SAFETY

Figure 5.1-4. Technology Evolution Issues

Five dominant technology requirements and six technologically most demanding service activities are listed below:

Dominant Technology Requirements

a) Structures and mechanisms
b) Automatic control, remote control and robotics
c) Instrumentation and telemetry
d) Command and data management
e) Crew training and procedures

Most Demanding Servicing Activities

a) SS modular buildup
b) Satellite assembly and test
c) Satellite refurbishment and repair (at SS and in situ)
d) Science requirement changeout
e) Materials processing sample changeout
f) Tethered operations

5.1.3 Time-Phased TDM Technology Evolution

Figure 5.1-5 shows the anticipated evolution of satellite servicing technology and space station servicing support capabilities, traced through a learning phase, an initial applications phase, and a subsequent operation phase. The time periods of this evolution are indicated and principal servicing operations and support requirements in each phase are summarized. Figure 5.1-6 shows milestones of this time-phased servicing technology evolution in terms of a projected schedule of shuttle and space station activities. Servicing activities on the shuttle began with milestone events indicated by ○ and starting with the launch

of two synchronous communication satellites in 1982 on STS 5. Those on the early SS are marked by △ symbols, starting in 1990-1991. In many instances the SS servicing activities evolve from those previously developed and demonstrated on the shuttle. The continuation of servicing activities, once developed, is indicated by solid or broken lines to the right of the initial events marked by ○ or △. These projections are based on data from TRW's current SS evolution study and also from the earlier satellite servicing users' model (SSUM) by Grumman Aerospace. Beyond 1996 the transition from the "early" to the more fully developed SS is expected to take place.

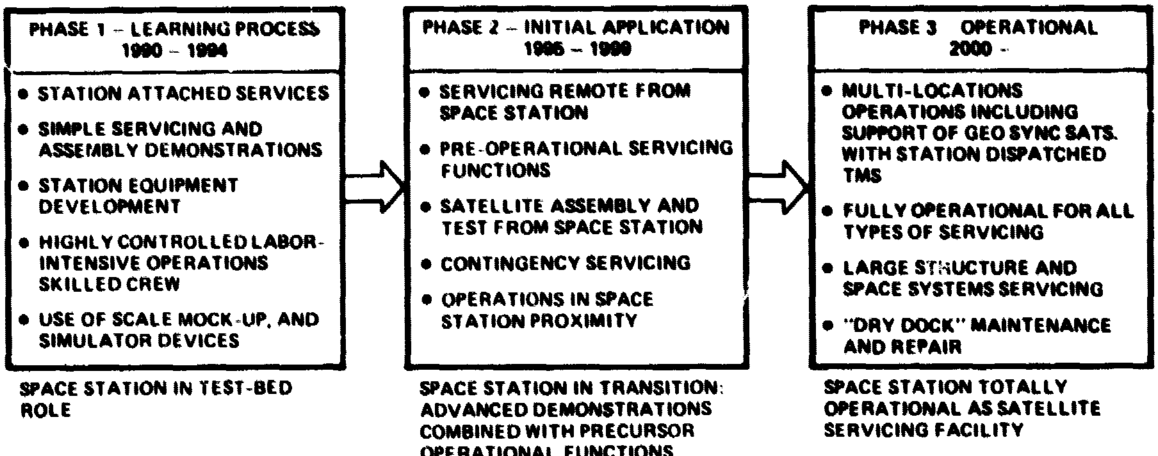

Figure 5.1-5. Evolution of Servicing Technology & Space Station Capability

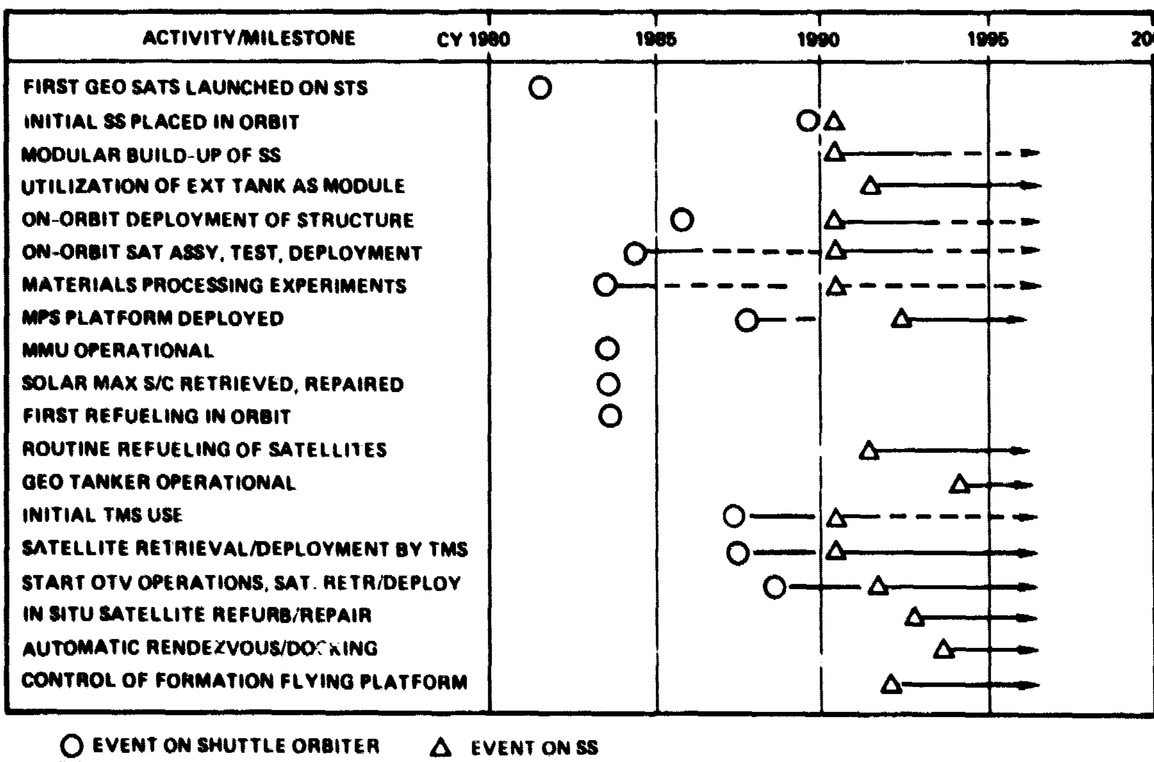

Figure 5.1-6. Servicing Technology Evolution on STS and Early SS

Figure 5.1-7 is a flow chart of on-going and projected major servicing technology events and activities. It delineates event sequences along three principal lines of evolution:

1) Servicing capabilities evaluation

2) On-orbit verification/capability growth

3) New technology demonstrations

The flow starts with precursor events such as demonstration on ground facilities, going back to the mid-70s, and continues through shuttle-based servicing technology evolution in the 80s, leading to SS-based further developments in the 90s. The chart presents specific examples of key events in technology development, support equipment utilization and support activities to major satellite programs. Some of these are reflected in the milestone schedule, Figure 5.1-6.

5.2 TECHNOLOGY DEVELOPMENT MISSION DEFINITION

Results of Study Task 2, definition and analysis of a set of sample TDMs, are summarized in this section. In this task we first identified 26 mission candidates among the three principal TDM categories. From these we chose five sample TDMs for further study and definition, using selection criteria that emphasize priority objectives of space station-based satellite servicing and needed technology developments. For each of these TDMs we then identified technology development areas/elements; determined precursor activity requirements, on the ground and/or on the shuttle orbiter; defined principal mission benefits; derived scenarios, mission sequences and operational details; and identified requirements on, and interfaces with the space station, including SS resource requirements to perform the TDMs. Crew functions, crew utilization and safety issues were a major concern in these analyses and task definitions.

5.2.1 TDM Candidate Mission Summaries

Figure 5.2-1 lists the 26 TDM candidate missions, their technology development/demonstration and operational mission support objectives. From this spectrum of TDM mission candidates a set of five example TDM missions were subsequently selected for further definition.

In our assessment, each of the candidate missions listed represents significant and partly overlapping concerns important to satellite servicing technology. For a choice of priority TDMs that could be addressed in detail within the framework of

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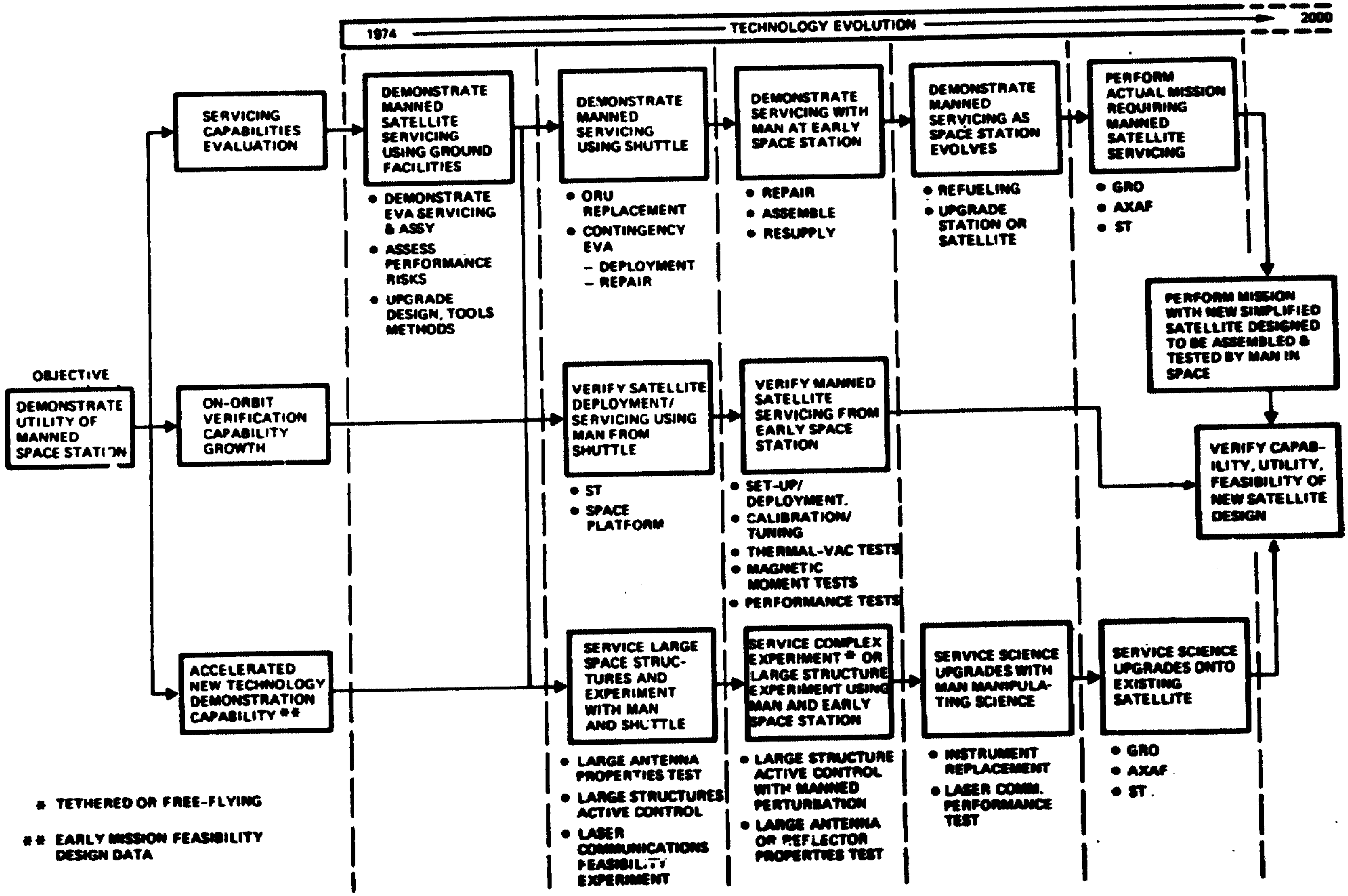

Figure 5.1-7. Evolutionary Development and Flight Demonstration Technology Plan

A. CATEGORY I – SS BUILDUP, MODIFICATION AND UTILIZATION

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
1. INCREASE SOLAR ARRAY SIZE	DEVELOP STRUCTURAL/ELECTR MODIFICATION TECHNIQUES	INCREASE OPERATING CAPACITY
2. INSTALL REMOTE MANIPULATOR ARM, SUPPORT RAIL, AND USE IN CARGO HANDLING AND CONSTRUCTION	DEVELOP ASSEMBLY TECHNIQUE	ADDED HANDLING CAPABILITY
3. ADD BERTHING PORT(S) FOR ORBITER, SATELLITES	DEVELOP ASSEMBLY TECHNIQUE	ADDED ACCESS TO SS
4. ADD CREW HABITABILITY MODULE(S)	ADVANCE CONSTRUCTION AND INTEGRATION TECHNOLOGY	PROVIDE FOR LARGER CREWS
5. ADD INFLATABLE HANGARS AND WORK STATIONS	ADVANCE CONSTRUCTION AND INTEGRATION TECHNOLOGY	ADDED OPERATING CAPABILITY
6. PREPARE MSS FOR LARGE STRUCTURE ASSEMBLY	DEVELOP ADDED SUPPORT TECHNOLOGY	PERFORM MISSION REQUIRING LARGE STRUCTURE ASSEMBLY

B. CATEGORY II – SPACECRAFT ASSEMBLY, TEST AND LAUNCH

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
1. ASSEMBLE SPACECRAFT FROM PREFAB MODULES AND PERFORM COMPLETE TEST/CHECKOUT	STRUCTURAL ASSEMBLY TECHNOLOGY AND INTERFACE CONTROL	REQUIRED IN A&T OF SATELLITES EXCEEDING SINGLE SHUTTLE LAUNCH CAPACITY
2. ASSEMBLE AND TEST LARGE SPACECRAFT STRUCTURES	ASSEMBLY AND TEST TECHNIQUES	SAME AS NO. 1
3. PERFORM APPENDAGE DEPLOYMENT IN EVA AND/OR BY REMOTE MANIPULATION	DEMONSTRATE/EVALUATE DEPLOYMENT SKILLS	SIMPLER DEPLOYMENT MECHANISMS, STRUCTURES
4. PERFORM SATELLITE ASSEMBLY WITH AID OF MANIPULATOR	DEMONSTRATE REMOTE CONTROL CAPABILITY	INTEGRATION OF SPACECRAFT MODULES TOO LARGE FOR CREW HANDLING

C. CATEGORY III – SATELLITE SERVICING, REFURBISHMENT AND REPAIR

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
1. MAINTAIN/UPGRADE ADVANCED SPACECRAFT	DEVELOP RETRIEVAL, HANDLING AND SERVICING TECHNIQUES	EXTEND ORBITAL LIFE OF SPACECRAFT SUCH AS GRO, LANDSAT
2. EXCHANGE OF SCIENCE INSTRUMENTS ON FACILITY-TYPE SPACECRAFT	DEMONSTRATE PRECISION ALIGNMENT AND INTEGRATION OF PAYLOAD ELEMENTS	NEEDED IN EFFECTIVE USE OF SPACE TELESCOPE, AXAF,GRO BY SCIENCE COMMUNITY
3. REPLACE FAILED/WORN ORUs	DEVELOP/DEMONSTRATE DIAGNOSTIC TECHNIQUES, HANDLING	ROUTINE REPAIR/REFURBISHMENT OF NEXT GENERATION SPACECRAFT
4. PERFORM FLUID TRANSFER (PROPELLANTS, COOLANTS, ETC) MANUALLY OR BY REMOTE CONTROL	DEVELOP/DEMONSTRATE SAFE FLUID TRANSFER METHODS	WILL BE NEEDED IN ROUTINE SPACE OPERATIONS IN LEO, GEO, ON S/C AND OTVs

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
7. PROVIDE COMMAND/CONTROL CAPABILITY FOR PROXIMITY OPERATIONS (FREE FLYERS, TMS)	EXPAND SS OPERATIONS TECHNIQUES AND CREW	ADDED SS CAPABILITY
8. EXERCISE FORMATION FLYING MODES OF UNMANNED PLAT-FORM, OTHER SUBSATELLITES	DEVELOP PRACTICAL/EFFICIENT PROXIMITY OPERATIONS MODES	ENHANCE SS OPERATION CAPA-BILITY IN USING FREE FLYING PLATFORM(S)
9. PROVIDE AND DEMONSTRATE AUTOMATED RENDEZVOUS/ DOCKING CAPABILITY	DEMONSTRATE AUTOMATED SATELLITE RETRIEVAL TECHNIQUES	USE DURING CARGO TRANSFER, TMS MISSIONS AND SATELLITE RETRIEVAL
10. ADD PROVISION FOR TETHERED PAYLOAD DEPLOYMENT AND CONTROL	DEMONSTRATE CONTROLLED TETHER DEPLOYMENT/ RETRACTION	USE IN TETHERED PAYLOAD MISSION
11. DEVELOP AND DEMONSTRATE GEO SATELLITE RETRIEVAL IN AEROBRAKING MODE	DEVELOP PRACTICAL FUEL EFFI-CIENT AEROBRAKING TECHNIQUE	RETRIEVE GEO SATELLITE FOR REFURBISHMENT AND REPAIR

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
5. DEPLOY LARGE ANTENNA STRUCTURE AND TEST RADIA-TION PATTERN	STRUCTURAL ASSEMBLY AND FORM CONTROL TECHNIQUES; MEASUREMENT BY FREE FLYER	REQUIRED IN NEXT GENERATION COMM SATELLITES AND RADIO ASTRONOMY MISSIONS
6. INTEGRATE LARGE SPACE STRUC-TURE WITH FREE FLYING SATEL-LITE CORE MODULE AND DEPLOY/ LAUNCH FROM MSS	DEVELOP ASSEMBLY, TEST AND LAUNCH TECHNIQUES OF LARGE STRUCTURES	SAME AS NO. 1, 2
7. PERFORM DISASSEMBLY OF SPACECRAFT FOR ON-STATION STORAGE OR RETURN TO GROUND	DEVELOP REMOTE AND MANUAL (EVA) MANIPULATION, TRANS-FER AND STORAGE TECHNIQUES	SUPPORT RE-USE OF EXISTING SPACE HARDWARE

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D REPAIR

TDM CANDIDATE MISSIONS	OBJECTIVES	
	TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	OPERATIONAL CAPABILITY AND MISSION PERFORMANCE
5. REPAIR/SERVICE FREEFLYING SATELLITE "IN SITU" BY REMOTE CONTROL	DEVELOP DIAGNOSTIC TECHNI-QUES AND REMOTE DELICATE HANDLING OPERATIONS	WILL BE NEEDED FOR SERVICE ON SATELLITES UNSUITABLE FOR DOCKING ON SS
6. REPAIR/SERVICE "IN SITU" WITH AID OF MANNED OTV, EVA OPERATIONS	DEVELOP/DEMONSTRATE CREW OPERATIONS REMOTE FROM SS	WILL BE USED FOR COMPLEX IN SITU SERVICING TASKS
7. RESUPPLY AND HARVEST PRODUCTS FROM FREE FLYING ZERO-G PROCESSING PLATFORM USING TMS	DEVELOP/DEMONSTRATE ACCESS TO AND REMOVAL/INSERTION OF SAMPLE MAGAZINES	NEEDED FOR ROUTINE OPERA-TION IN FF COMMERCIAL PROCESSING PLATFORMS
8. RETRIEVE AND PREPARE A S/C FOR RETURN TO GROUND VIA ORBITER	DEVELOP RETRIEVAL TECHNIQUES	WILL BE USED IN RETURNING SATELLITES FOR REFURBISHMENT ON GROUND

2

FOLDOUT FRAME

Figure 5.2-1. TDM Candidates

this study we defined specific selection criteria, with the concurrence of the MSFC study manager.

5.2.2 Overview of TDM Selection

The criteria and selection factors which we formulated to guide the selection of specific sample TDM missions are listed below. The principal criteria are to be met by the candidate missions to qualify for selection. The "Other Selection Factors" also express important considerations in the systematic selection process.

Principal Criteria

a) Performs useful operational mission

b) Serves to enable/enhance servicing technology

c) Combines several technology development objectives

d) Is realistic as to projected cost, schedule and support equipment

Other Selection Factors

e) Crew utilized effectively

f) Required operations exceed orbiter stay time

g) Evolutionary growth potential

h) Involves significant new technology, design or operation

i) Satisfies several program objectives

j) Supports variety of operations/ experiments or missions

The selected five TDMs are listed below along with the rationale for their selection.

	SELECTED TDM	RATIONALE
CAT. I	1. BUILD-UP OF SPACE STATION MANIPULATOR CAPABILITY	• ESSENTIAL TO SS ASSEMBLY AND CARGO HANDLING CAPABILITY
CAT. II	2. ON-ORBIT SPACECRAFT ASSEMBLY, TEST AND LAUNCH	• BASIC STEP IN ALL FUTURE A&T MISSION ON SS • FOLLOW-ON TO EARLIER ORBITER BASED MISSIONS
	3. LARGE ANTENNA STRUCTURE DEPLOYMENT	• REPRESENTATIVE OF SPACE-BASED ACTIVITIES NOT FEASIBLE ON GROUND • NEEDED IN MANY FUTURE COMMUNICATIONS AND EARTH OBSERVATION MISSIONS
CAT. III	4. SERVICE/REFURBISH SATELLITE (GRO)	• MAKE EXTENDED USE OF GRO POSSIBLE
	5. SERVICING OF FREE-FLYING MATERIALS PROCESSING PLATFORM	• NEEDED TO SUPPORT ROUTINE COMMERCIAL SPACE PROCESSING

Figure 5.2-2 shows the selected TDMs by outline sketches to illustrate some salient points. In three of these missions dealing with assembly, deployment or refurbishment/repair of satellites or space structures (TDM 2, TDM 4 and TDM 3, respectively) an early space station configuration is assumed of the type identified in TRW's concurrent Space Station Needs, Attributes and Architectural Options Study for NASA Headquarters. These configurations provide the necessary resources to support as well as accommodate the TDMs in question. The manipulator track installation, TDM 1, is shown on a reconfigured space station, with the shuttle orbiter at one of the available berthing ports supporting the construction task. The illustration of TDM 5, servicing of a free-flying materials processing platform with aid of the TMS, only shows that platform and the TDM approaching it for removal/replacement of a sample magazine or payload module. The concept shown here derives from TRW's earlier (1979-1981) conceptual design studies of a 25 kW Space Platform and a Materials Experiment Carrier (MEC) attached to that platform. Both studies were performed under NASA/MSFC contracts (NAS8-33956 and NAS8-33688).

Subsequent sections will present in some detail the implementation, mission sequences, scenario highlights, interfaces and support requirements, precursor missions, and overall mission benefits of each of these TDMs.

5.2.3 TDM 1, Build-Up of Space Station Manipulator Capability

TDM 1 involves the construction of a track system to support a movable manipulator arm on the early space station. A fixed manipulator arm is assumed to be in place prior to the start of this mission. The track system is assembled on-orbit from small parts delivered by the STS. A later STS flight assists in transferring the space station manipulator arm to the track system, using the orbiter's RMS.

This TDM requires significant construction and assembly operations on the space station. It enhances the capability of the space station and forms an experience base for similar, future operations on the space station and in space, generally.

Figure 5.2-3 summarizes the results of our TDM 1 mission definition and implementation study.

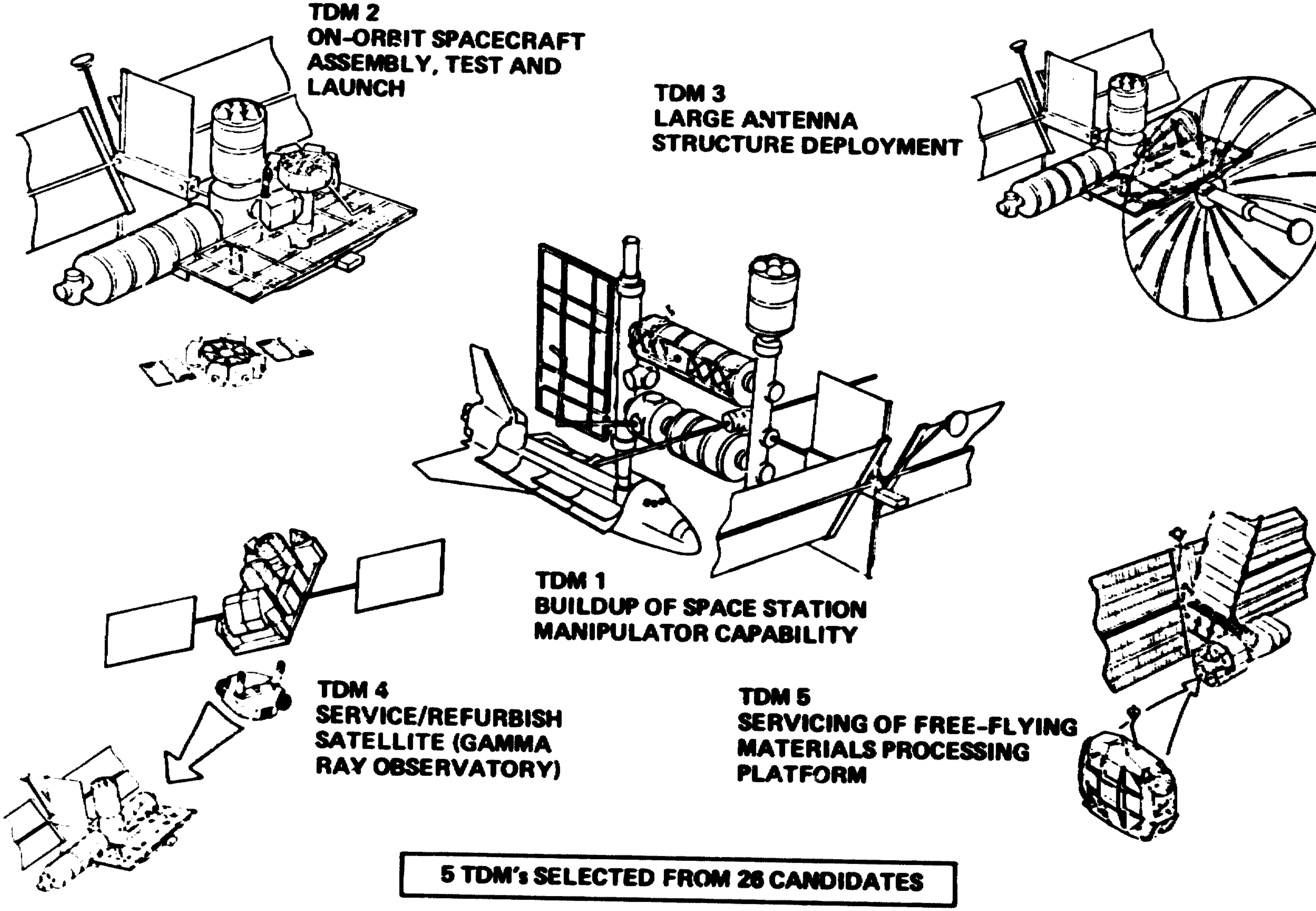
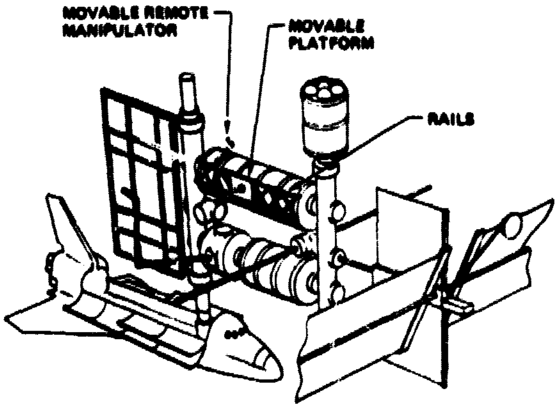


Figure 5.2-2. Satellite Servicing Study TDMs

A. TDM NO. 1 SUMMARY



1. TECHNOLOGY DEVELOPMENT AREAS
   - LARGE STRUCTURE ASSEMBLY IN SPACE
   - ADVANCED EVA TECHNOLOGIES
   - ADVANCED CREW SUPPORT SYSTEMS
   - ADVANCED MANIPULATOR USES
   - ON ORBIT SYSTEM/SUBSYSTEM TEST
   - SPACE STATION INSTALLATIONS

2. BENEFITS
   - DEVELOP ON ORBIT ASSEMBLY TECHNIQUES
   - ENHANCE SS LOAD HANDLING CAPABILITY
   - SUPPORT SUBSEQUENT SS MODIFICATIONS

3. SPACE STATION REQUIREMENTS SUMMARY
   - STORAGE PROVISIONS ON SS FOR BUILDING MATERIALS
   - SPECIAL CREW TRAINING, PROCEDURES
   - SPECIAL CREW SUPPORT EQUIPMENT, INSTALLATION TOOLS
   - AUTONOMOUS MISSION SUPPORT SYSTEMS

4. SCENARIO HIGHLIGHTS
   - SHUTTLE DELIVERS RMS, RAILS AND OTHER BUILDING MATERIAL
   - SHUTTLE RMS ASSISTS EVA CREW IN CONSTRUCTION
   - CREW COMPLETES INSTALLATION, PERFORMS CHECKOUT AND FUNCTIONAL TESTS

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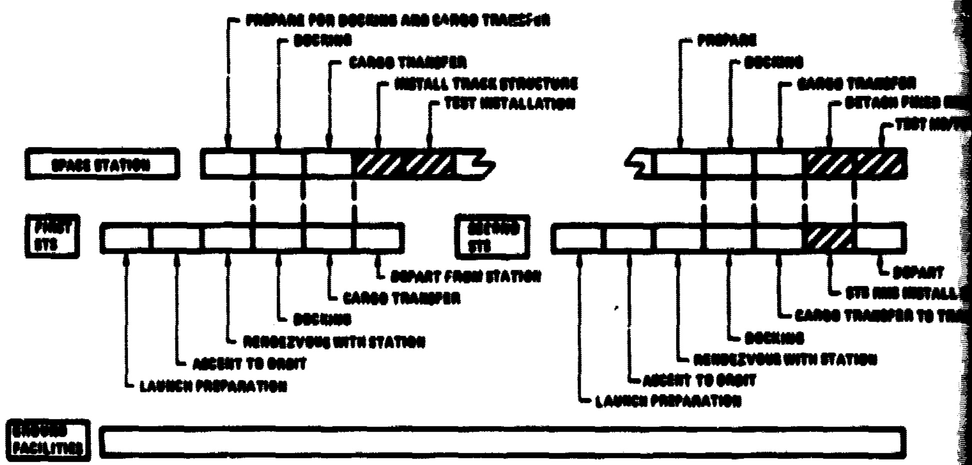
B. MISSION SEQUENCE



D. KEY TDM PRECURSORS

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STA
1. LARGE STRUCTURE ASSEMBLY	• MODELING AND SIMULATION • UNDERWATER TESTS	• DEMONSTRATION OF ASSEMBLY TECHNIQUES ON ORBITER, e.g., STRUCTURAL ASSEMBLY DEMONSTRATION EXPERIMENT (SADE)	(B) PROJ ~ 198
2. UTILIZATION OF RMS WITH CHERRY PICKER	• SIMULATION INCLUDING CREW TASK HANDLING	• DEMONSTRATION ON ORBITER	(B) PROJ START (SOLA
3. RMS MANIPULATION OF LARGE PAYLOAD	• SIMULATION • RMS ENGINEERING SIMULATOR EXPERIMENTS	• HANDLING OF LDEF	(B) PROJ 1984
4. MULTIPLE RMS OPERATION IN P/L HANDLING/POSITIONING	• SIMULATION • RMS ENGINEERING SIMULATOR EXPERIMENTS	• DEMONSTRATION ON ORBITER	CONC
5. UTILIZATION OF HUD[1]	• CREW PERFORMANCE MEASUREMENT ON VARIOUS HUD IMPLEMENTATIONS	• DEMONSTRATE HUD ON OPERATIONAL EVA TASKS IN ORBITER BAY	CONC

[1]HUD – HEADS UP DISPLAY IN ASTRONAUT EMU HELMET

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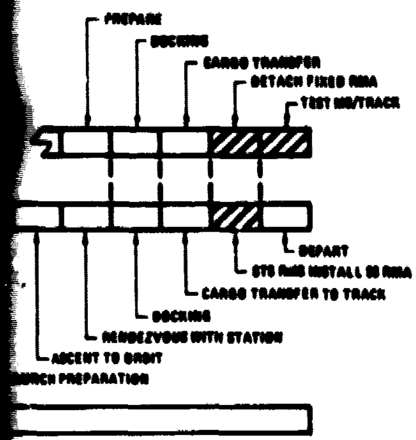

C. INTERFACES AND SUPPORT REQUIREMENTS

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED EXISTING
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
CARGO STORAGE FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE TRACK STRUCTURE AND CONTROL SYSTEM		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT CONSTRUCTION OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
TRACK SYSTEM TEST SET	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	

(S) STS PRECURSOR	STATUS
• DEMONSTRATION OF ASSEMBLY TECHNIQUES ON ORBITER, e.g., STRUCTURAL ASSEMBLY DEMONSTRATION EXPERIMENT (SADE)	(S) PROJECTED ~ 1985
• DEMONSTRATION ON ORBITER	(S) PROJECTED START 1984 (SOLAR MAX)
• HANDLING OF LDEF	(S) PROJECTED 1984
• DEMONSTRATION ON ORBITER	CONCEPT
• DEMONSTRATE HUD ON OPERATIONAL EVA TASKS IN ORBITER BAY	CONCEPT

E. KEY TDM BENEFITS

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TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. LARGE STRUCTURE ASSEMBLY	• USERS IN ERA OF LARGE SCALE CONSTRUCTION JOBS ON SS • RAIL SYSTEM INCREASES RMS ACCESS AND REACH, ENHANCES FLEXIBILITY OF OPERATIONS
2. UTILIZATION OF RMS WITH CHERRY PICKER	• ENHANCES CREW CAPABILITY AND OPERATING MODES • ENHANCES SAFETY OF RMS OPERATIONS REMOTE FROM CONTROL STATION
3. RMS MANIPULATION OF LARGE PAYLOAD	• FACILITATES SATELLITE ASSEMBLY • ESSENTIAL TO MSS RECONFIGURATION TASKS • ESSENTIAL TO BERTHING OF RETRIEVAL SATELLITES, TMS, OTV; ALSO FACILITATES ORBITER BERTHING • PERMITS THRUST-FREE SATELLITE DEPLOYMENT VIA GRAVITY GRADIENT MODE • CONTROL DYNAMICS DEMONSTRATION
4. MULTIPLE RMS OPERATION	• INCREASED P/L HANDLING FLEXIBILITY AND CONTROL
5. UTILIZATION OF HUD IN EVA TASKS	• ENHANCES CREW PRODUCTIVITY/EFFECTIVENESS, SAVES TIME AND TRAINING COST • REDUCES HUMAN ERROR RISK • ENHANCES CREW SAFETY

OVERALL TDM BENEFIT – ENHANCES SS OPERATION CAPABILITY AND FLEXIBILITY AND AIDS SS EVOLUTIONARY GROWTH

Figure 5.2-3. Build-up of Space Station Manipulator Capability (TDM 1)

2 FOLDOUT FRAME

The technology development areas listed in Figure 5.2-3A identify broad technology areas in this mission and summarizes the TDM benefits, scenario highlights and space station resources required to support the mission.

Figure 5.2-3B summarizes mission sequences on the space station, the STS, and ground facilities. Those phases which must be synchronized between different elements are connected with dashed lines.

Operations are relatively autonomous from detailed ground direction and control. Ground facility involvement in detailed operations should only be required in the event of anomalies.

Figure 5.23-C identifies the major operational and physical interfaces for space station support for this mission. Also listed are the support services and equipment required for this mission. These services and equipment are peculiar to this mission and must be included in the mission cost.

Figure 5.2-3D identifies ground-based and shuttle orbiter-based precursors. Precursor activities on the ground include modeling and simulation of large structure assembly, use of the remote manipulators, and crew performance observations in underwater tests. Of particular interest in these and other precursor activities is the use of heads-up displays (HUD) for more efficient, time saving and error free crew operations. Careful preparation and performance of precursor activities for each technology development element (TDE) on the ground and on-orbit will be a key to achieving a successful TDM on-board the space station and thus lead the way to cost and time efficient utilization of the SS in the required construction tasks.

Figure 5.2-3E lists the principal TDM benefits in the evolution and growth of the space station itself and in enhancing its utility of supporting satellite launch and repair/refurbishment activities such as the increased support a movable manipulator provides to EVA crew operations.

5.2.4 TDM 2, On-Orbit Spacecraft Assembly, Test and Launch

This TDM involves on-orbit assembly, test, fueling, and launch of a modular spacecraft that may exceed the weight or volume capacity of a single shuttle launch or which has been designed to be carried to orbit partially assembled. Many on-orbit operations are touched by this TDM including those also directly related to servicing such as ORU

installation, inspection, deployment of appendages, propellant loading, checkout, and launching from a space station. This mission is particularly suited for the space station because of the time required to complete all procedures, and because of the storage, power, and other support facilities required. Figure 5.2-4A summarizes the mission definition and implementation study results. Figure 5.2-4B details the mission sequences which after shuttle orbiter departure become non-time-critical.

A key feature of this mission is the independence from the ground facilities of the targeting and launch of the free-flyer spacecraft (barring anomalies). Because the launch of the spacecraft into its transfer orbit does not involve scheduling extensive facilities and large numbers of people, the launch date and time can be much less critical. Also, because final spacecraft testing is done in orbit, and because transfer orbit injection can be delayed until all anomalies are resolved, probability of mission success will be improved.

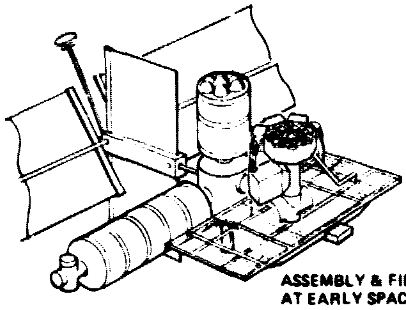
Figure 5.2-4C summarizes major operational and physical interfaces. In Figure 5.2-4D ground-based precursor tasks are listed for four of the technology development elements, while shuttle-based precursors are listed for all. Underwater tests will be used to evolve and demonstrate crew procedures. Other ground tests, to be performed on the air bearing simulator, will demonstrate operation of the open cherry picker. As in TDM 1, the use of the HUD techniques will be refined on the ground and in preparation of utilization in orbital missions.

Figure 5.2-4E summarizes mission benefits accrusing from this TDM. Of particular interest are those TDEs (1 through 5) that directly serve to enhance crew capability, efficiency and productivity. As such they overlap with the TDE benefits provided by and previously discussed under TDM 1.

5.2.5 TDM 3, Large Antenna Structure Deployment

Construction of large antennas in orbit involves problems in achieving precise geometries of large structures and in measuring and adjusting the antenna pattern. Far field measurements may require the test receiver to be many miles from the antenna. Because of the deforming effects of gravity on the ground, final antenna geometry adjustments are best done on orbit. This TDM is designed to develop the technol-

A. TDM NO. 2 SUMMARY

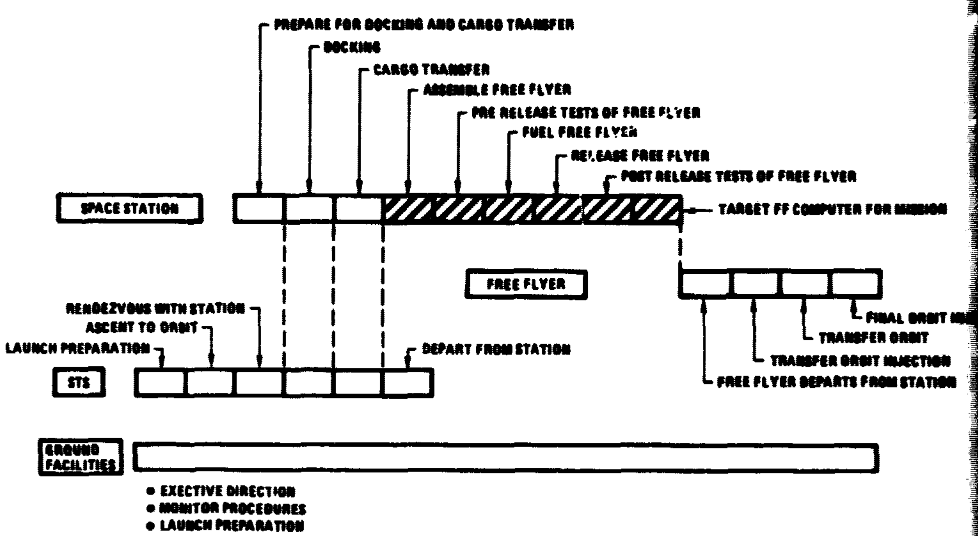


ASSEMBLY & FINAL TEST
AT EARLY SPACE STATION

FREE FLYERS/PLATFORMS

1. TECHNOLOGY DEVELOPMENT AREAS
   - EVA TECHNOLOGIES
   - ON ORBIT SPACECRAFT ASSEMBLY
   - ON ORBIT REFUELING
   - ON ORBIT SYSTEM/SUBSYSTEM TEST
   - RMA HANDLING METHODOLOGIES
2. BENEFITS
   - FINAL TEST ON ORBIT IMPROVES PROBABILITY OF MISSION SUCCESS
   - SPACECRAFT MAY EXCEED STS SIZE AND WEIGHT LIMITS
3. SPACE STATION REQUIREMENTS SUMMARY
   - STORAGE PROVISIONS ON SPACE STATION
   - MODULE HANDLING BY RMS, AIDED BY CREW (EVA)
   - MECHANICAL AND ELECTRICAL FSE (GENERAL AND SPECIAL PURPOSE) NEEDED
   - SPECIALIZED CREW TRAINING, CREW SUPPORT EQUIPMENT
   - STANDARDIZED INTERFACE DESIGN
   - AUTONOMOUS MISSION SUPPORT SYSTEMS
4. SCENARIO HIGHLIGHTS
   - SPACECRAFT MODULES DELIVERED ON SUCCESSIVE SHUTTLE VISITS
   - STORED ON-BOARD SPACE STATION
   - ASSEMBLED, CHECKED-OUT, TESTED BY SS CREW, PARTLY IN EVA MODE
   - CREW ASSISTS IN APPENDAGE DEPLOYMENT
   - CREW PREPARES SPACECRAFT FOR AND ACCOMPLISHES LAUNCH

B. MISSION SEQUENCES



D. KEY TDM PRECURSORS

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	STATU
1. ORU REPLACEMENT IN EVA MODE	• UNDERWATER TEST	• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) PROJECT 1984 ON MMS
2. SPECIALIZED CREW SUPPORT EQUIPMENT DEVELOPMENT AND TEST	• UNDERWATER TESTS	• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) START MID-
3. DEMONSTRATION OF CHERRY PICKER IN SAT ASSEMBLY[1]	• SIMULATOR	• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) PROJECT START
4. DEMONSTRATION/USE OF HANDLING AIDS		• USE ON ORBITER MISSION(S)	(B) PROJECT LATE
5. FLUID TRANSFER		• TEST AND DEMONSTRATION ON PROTOTYPE UNIT • USE ON SATELLITE REFUELING MISSION	(B) 1984 (B) CONCE
6. UTILIZATION OF HUD IN EVA MODE[2]	• GROUND-BASED EVALUATIONS	• TEST AND UTILIZE HUD TECHNIQUES	CONCEPT
7. FULL-SCALE ASSEMBLY/TEST AND LAUNCH OF STS-DEPLOYED SATELLITE		• UTILIZATION ON ORBITER MISSIONS (INCLUDING RMS DEPLOYMENT AND SEPARATION OF SATELLITE)	CONCEPT

[1]SEE ALSO TDM-1, NO. 2 [2]SEE ALSO TDM-1, NO. 5

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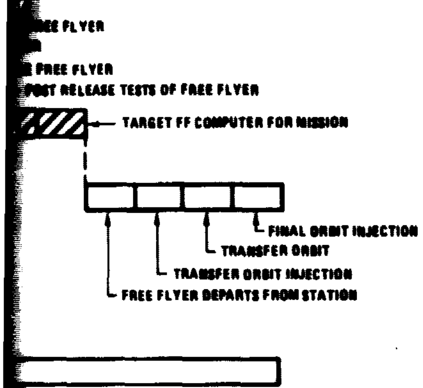

C. MISSION INTERFACES AND SUPPORT REQUIREMENTS

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO MODULAR SPACECRAFT	●		●	
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
COMMAND/TELEMETRY LINK FROM SPACE STATION TO MODULAR SPACECRAFT	●		●	
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE MODULAR SPACECRAFT AND SUPPORT EQUIPMENT		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT CONSTRUCTION OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
SPACECRAFT TEST/COMMUNICATIONS EQUIPMENT FOR SPACE STATION	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	
SPACECRAFT MISSION TARGETING COMPUTER FOR SPACE STATION	●		●	

(B) STS PRECURSOR	STATUS
• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) PROJECTED 1984 ON MMS
• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) START IN MID-80s
• DEMONSTRATION AND USE ON ORBITER MISSION(S)	(B) PROJECTED START 84
• USE ON ORBITER MISSION(S)	(B) PROJECTED LATE 80s
• TEST AND DEMONSTRATION ON PROTOTYPE UNIT • USE ON SATELLITE REFUELING MISSION	(B) 1984 (B) CONCEPT
• TEST AND UTILIZE HUD TECHNIQUES	CONCEPT
• UTILIZATION ON ORBITER MISSIONS (INCLUDING RMS DEPLOYMENT AND SEPARATION OF SATELLITE)	CONCEPT

E. KEY TDM BENEFITS

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TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. ORU REPLACEMENT IN EVA MODE	• ESSENTIAL ELEMENT IN ASSEMBLY, SERVICING AND REPAIR OF SATELLITES BY CREW
2. SPECIALIZED CREW SUPPORT EQUIPMENT DEVELOPMENT	• ENHANCES CREW EFFECTIVENESS AND SAFETY
3. USE OF CHERRY PICKER	• SAME AS TDM-1, NO. 2
4. USE OF HOLDING FIXTURE	• INCREASED P/L HANDLING FLEXIBILITY AND CONTROL
5. FLUID TRANSFER	• ESSENTIAL TO MOST SATELLITE SERVICING MISSIONS, INCLUDING PROPELLANT AND COOLANT TRANSFER OR RELOADING
6. HUD UTILIZATION IN EVA	• SAME AS TDM-1, NO. 5
7. PRIOR DEMONSTRATION OF OF SATELLITE ASSEMBLY TEST AND LAUNCH ON STS	• USHERS IN ERA OF SATELLITE ON-ORBIT ASSEMBLY • INCREASES EFFICIENCY OF LARGER SCALE ASSEMBLY ON SS

OVERALL TDM BENEFIT – ESTABLISHES SS AS OPERATIONAL BASE BEYOND STS FOR DEPLOYING LARGE SATELLITES

FOLDOUT FRAME 2

Figure 5.2-4. On-Orbit Spacecraft Assembly, Test and Launch (TDM 2)

ogies required for these operations.

The mission features an antenna support structure designed to isolate the antenna dish from space station disturbance torques, and a self-deploying antenna dish. Structural members added by EVA, after dish deployment, increase overall structural stiffness of the antenna.

Figure 5.2-5A summarizes the mission concept; Figure 5.2-5B shows a summary of mission sequences. Figure 5.2-5C indicates interface and support requirements. Some of the mission tasks are difficult to accomplish and require considerable mission peculiar support and test equipment, extensive planning of crew functions and procedures.

Figure 5.2-5D lists TDEs concerning antenna dish deployment, shape measurement and control, measurement of the antenna beam pattern and demonstration of the antenna which are suitable for precursor demonstrations on the ground or on the shuttle orbiter. The most important, last entry in this chart involves antenna performance verification, a mission-related task, such as wide-band communication to a distant probe or subsatellite. Structural deformations due to pointing dynamics and thermal transients on entering and leaving solar eclipses are of principal concern for the proposed large (60 m) antenna diamter.

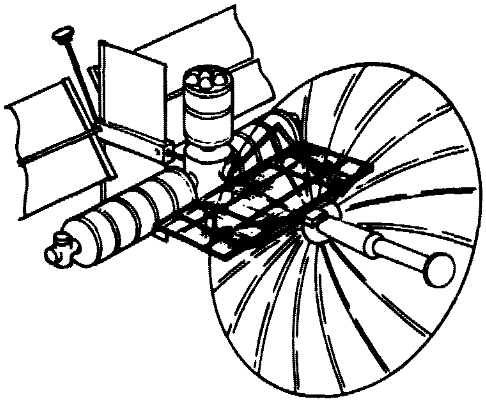
A ground-based series of antenna shape measurements and control demonstrations have already been performed by NASA/LsRC, with subsequent test series in progress at Harris Aerospace Company.

The overall benefit of this TDM (Figure 5.2-5E) is the establishment of the new technology of deploying/erecting large, high-precision structures such as antennas with diameters in excess of 20 m. Also it directly serves several new and ambitious space mission categories that depend critically on the availability of large antenna reflectors (e.g., radio astronomy, microwave radiometery, space-based radar and mobile unit satellite communication by spot beams).

5.2.6 TDM 4, Service and Refurbishment of an Existing Satellite

This mission makes use of an existing satellite such as the Gamma Ray Observatory (GRO) at its planned end of life. Because mission time constraints are not significant compared to a shuttle mission, even units not designed for on-orbit repair may be serviceable. This mission may be thought of as a generic on-orbit satellite refurbishment mission for the space station. Its

A. TDM NO. 3 SUMMARY



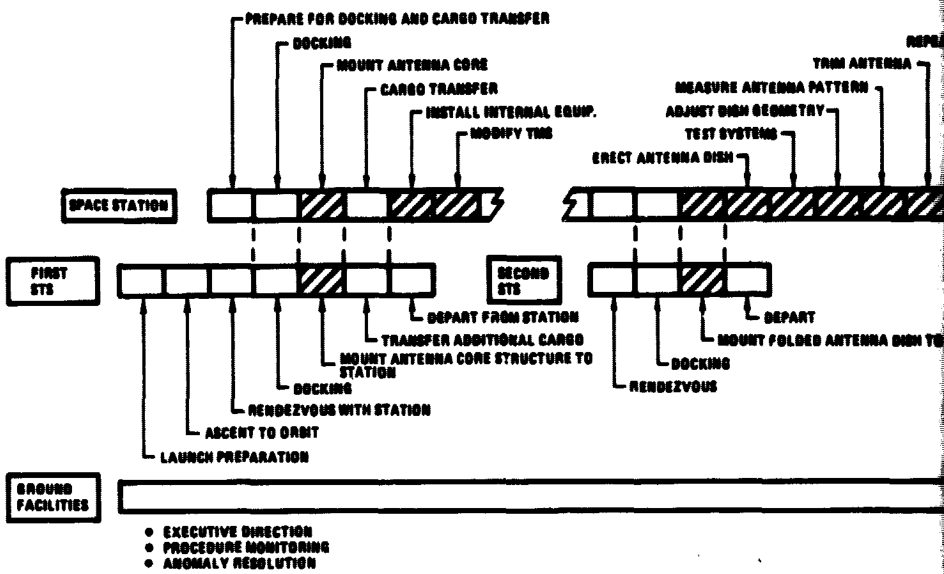
1. TECHNOLOGY DEVELOPMENT AREAS
   - EVA CONSTRUCTION
   - TMS OPERATIONS
   - AUTOMATFD ANTENNA SHAPE CONTROL
   - MEASUREMENT & TEST OF LARGE STRUCTURE DYNAMICS
   - ON-ORBIT SYSTEM/SUBSYSTEM TEST
   - REMOTE RF MEASUREMENTS

2. BENEFITS
   - ANTENNAS MAY EXCEED SIZE AND WEIGHT LIMITATIONS OF SHUTTLE
   - PRECISE GEOMETRIES MAY BE ACHIEVED

3. SPACE STATION REQUIREMENTS SUMMARY
   - SPECIALIZED MECHANICAL AND CREW SUPPORT EQUIPMENT
   - OPTICAL/LASER SHAPE MONITORING
   - SHAPE CONTROL TECHNIQUES
   - PRECISION TRACKING AND CONTROL OF FREE FLYING (TMS) RECEIVER LOCATION
   - SPECIALIZED CREW TRAINING
   - AUTONOMOUS MISSION SUPPORT SYSTEMS

4. SCENARIO HIGHLIGHTS
   - SHUTTLE DELIVERS FOLDED ANTENNA STRUCTURE
   - CREW ERECTS ANTENNA DISH, AIDED BY LASER OR PASSIVE OPTICAL MEASUREMENTS
   - FREE FLYING PROBE (TMS) MEASURES ANTENNA PATTERN
   - ANTENNA TRIMMING AS REQUIRED

B. MISSION SEQUENCE



D. KEY TDM PRECURSORS

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR	ST
1. ON-ORBIT DEPLOYMENT/ ERECTION OF LARGE ANTENNA STRUCTURE (AUTOMATIC/EVA ASSISTED)	• DEMONSTRATE WITH STRUCTURAL MODEL ON TEST STAND (SMALLER ANTENNA SIZE)	• SEVERAL ANTENNA DEPLOYMENT DEMONSTRATIONS ON ORBITER (UP TO 20M DIAMETER)	(A) MID (B) LAT
2. DEMONSTRATE/VERIFY ON-ORBIT LARGE ANTENNA SHAPE MEASUREMENT AND CONTROL TECHNIQUES	• GROUND DEMONSTRATIONS PERFORMED ON SMALLER ANTENNAS AT LaRC (1981)	• DEMONSTRATIONS ON-BOARD SHUTTLE ORBITER (SMALLER ANTENNA SIZE)	(B) MID
3. MEASURE ANTENNA BEAM PATTERN BY FREE FLYING PROBE	• CONVENTIONALLY PERFORMED ON SMALLER ANTENNAS (ANTENNA TEST FACILITY)	• PRECISION TRACKING AND POSITION CONTROL OF FREE-FLYING PROBE (e.g., MANEUVERING CAMERA UNIT	(B) PRO MID
4. DEMONSTRATE ANTENNA BEAM STEERING	-	-	
5. DEMONSTRATE/VERIFY ANTENNA PERFORMANCE IN MISSION RELATED TASKS	• DEMONSTRATE ON LARGE GROUND ANTENNAS	• DEMONSTRATE ON SMALLER ANTENNAS DEPLOYED FROM ORBITER	(B) MID

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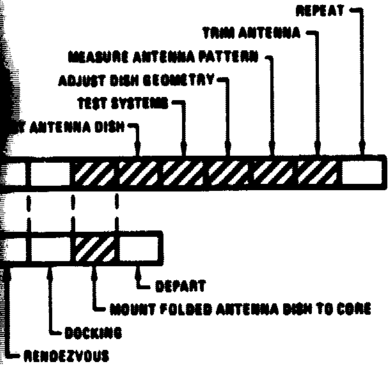

(B) STS PRECURSOR	STATUS
• SEVERAL ANTENNA DEPLOYMENT DEMONSTRATIONS ON ORBITER (UP TO 20M DIAMETER)	(A) MID-80s (B) LATE 80s
• DEMONSTRATIONS ON-BOARD SHUTTLE ORBITER (SMALLER ANTENNA SIZE)	(B) MID-1980s
• PRECISION TRACKING AND POSITION CONTROL OF FREE-FLYING PROBE (e.g., MANEUVERING CAMERA UNIT	(B) PROJECTED MID-80s
• DEMONSTRATE ON SMALLER ANTENNAS DEPLOYED FROM ORBITER	(B) MID-80s

C. MISSION INTERFACES AND SUPPORT REQUIREMENTS

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
CARGO STORAGE FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE TRACK STRUCTURE AND CONTROL SYSTEM		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT CONSTRUCTION OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
TRACK SYSTEM TEST SET	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	

E. KEY TDM BENEFITS

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. DEMONSTRATE ON-ORBIT DEPLOYMENT/ERECTION OF LARGE ANTENNA STRUCTURE (AUTOMATIC/EVA ASSISTED)	• ENABLES CONSTRUCTION OF LARGE ANTENNAS FOR RADIO ASTRONOMY, MICROWAVE RADIOMETRY, SPACE-BASED LASER, MOBILE SATELLITE COMM • DEMONSTRATES AUTOMATIC AND MANUALLY ASSISTED ANTENNA DEPLOYMENT TECHNIQUES
2. DEMONSTRATE/VERIFY ON-ORBIT LARGE ANTENNA SHAPE MEASUREMENT AND CONTROL TECHNIQUES	• VERIFIES ACHIEVEMENT OF SPECIFIED ANTENNA SHAPE
3. MEASURE ANTENNA BEAM PATTERN BY FREE-FLYING PROBE (e.g., TMS)	• VERIFIES ANTENNA PATTERN IN NEAR OR FAR FIELD • ESTABLISHES/VERIFIES PRECISION CONTROL OF FREE FLYING PROBES
4. DEMONSTRATE/VERIFY ANTENNA PERFORMANCE IN MISSION-RELATED TASKS, e.g. RADIO ASTRONOMY, SPOT BEAM COMMUNICATION, MICROWAVE RADIOMETRY	• VERIFIES OVERALL ANTENNA PERFORMANCE IN OPERATING MODES DICTATED BY MISSION PROFILE (SEE ITEM 1)

OVERALL TDM BENEFIT – DEMONSTRATES AND VERIFIES ON-ORBIT CONSTRUCTION, MEASUREMENT AND CONTROL OF LARGE ANTENNAS NEEDED IN RADIO ASTRONOMY, MICROWAVE RADIOMETRY (GROUND OBSERVATION), SPACE-BASED RADAR, MOBILE COMM SATELLITE MISSIONS

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Figure 5.2-5. Large Antenna Structure Deployment (TDM 3)

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characteristics are summarized in Figure 5.2-6A.

The GRO, which is in about the same orbit as the space station, is retrieved by the TMS. One secured to the station, the GRO can be inspected, tested, disassembled and repaired. The space station can wait for delivery of parts or modules which are determined to need replacement. After repair, refurbishment and refueling the GRO will be redeployed by the TMS for an extension of its planned mission.

Figure 5.2-6B shows the mission sequence including operations by the SS, the TMS, and ground facilities. Figure 5.2-6C indicates mission interfaces and support requirements. Mission peculiar space station interfaces are the satellite berthing area, power and data lines, and a fuel transfer facility. Support services and equipment for this mission depend upon what needs to be done to refurbish the GRO.

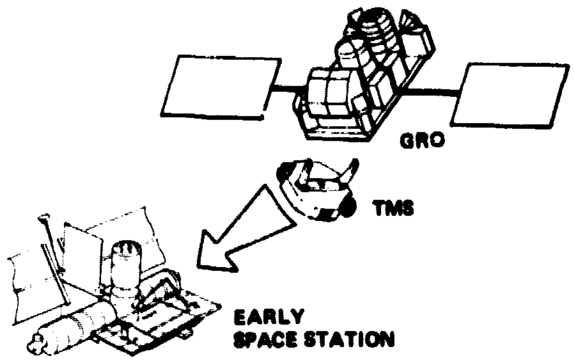
Together with TDM 5 (Servicing of a Materials Processing Platform) this TDM will involve servicing operations most frequently required in the era of the manned space station. Ground-based tests and simulations will therefore be important precursors in the evolution of the servicing techniques requires (see Figure 5.2-6E). All of these are principal on-orbit servicing tasks as commonly viewed by system planners and project managers. This TDM therefore is one of the most important ones in the entire range of TDM candidates investigated. It also tends to be among the most complex and diversified technology developments.

The five TD elements identified in the chart emphasize crew procedures, crew support equipment, and crew utilization modes (e.g., heads-up display provisions) and overlap in part with TDEs called out in the preceding TDMs. A key benefit of establishing such procedures by TDM 4 is to gain increased confidence in planning for future use of on-orbit maintenance activities as a routine assignment to the SS crew. It thus provides a critical shake-down or "debugging" phase in the overall evolution of man-in-space technology and space station capability.

5.2.7 TDM 5, Servicing of Free-Flying Materials Processing Platform (MPP)

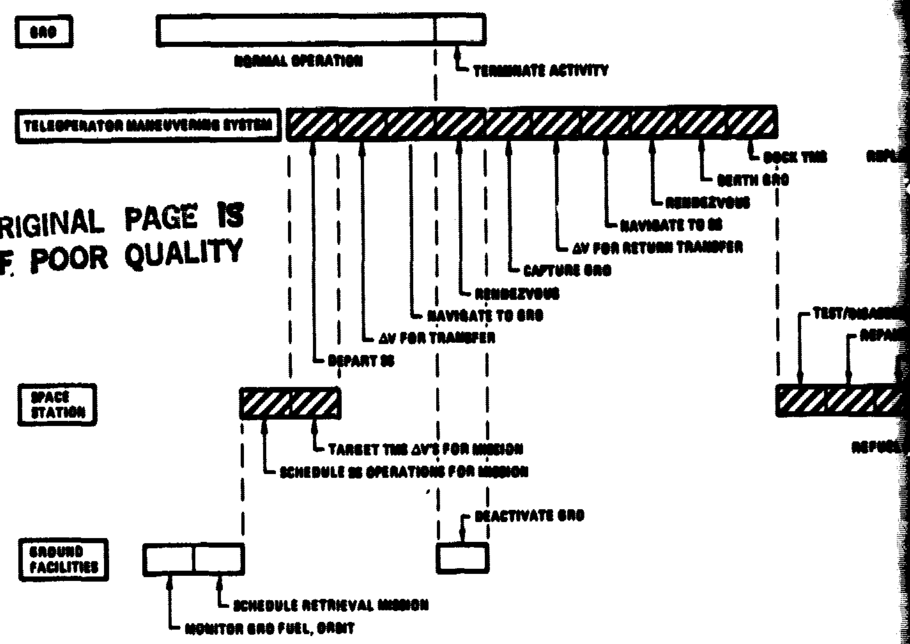
Figure 5.2-7A summarizes the characteristics of the free-flying materials processing platfrom servicing mission. This TDM differs from the first four in that it is an open ended, pilot plant operation which can develop into a continuous operational mission. Only one ser-

A. TDM NO. 4 SUMMARY



1. TECHNOLOGY DEVELOPMENT AREAS
   - EVA CONSTRUCTION/DISASSEMBLY
   - ON ORBIT FLUID TRANSFER/STORAGE
   - TMS OPERATIONS
   - PART REPLACEMENT
   - CONTINGENCY SERVICE OPERATIONS
   - ON ORBIT SYSTEM/SUBSYSTEM TEST
   - SATELLITE RETRIEVAL
   - ADVANCED CREW SUPPORT TECHNOLOGIES
2. BENEFITS
   - EXTENSION OF LIFE OF GRO
   - APPLICABLE TO REPAIR/REFURBISHMENT OF MANY OTHER S/C
3. SPACE STATION REQUIREMENTS
   - MECH AND ELECT SUPPORT EQUIPMENT
   - CREW SUPPORT EQUIPMENT
   - REFILLABLE PROPELLANT TANKS
   - SPECIAL CREW TRAINING
   - AUTONOMOUS MISSION SUPPORT SYSTEMS
4. SCENARIO HIGHLIGHTS
   - GRO RETRIEVED FROM 400 KM ORBIT
   - COMPREHENSIVE STATUS TESTS
   - REFURBISHMENT/REPAIR OF UNITS
   - PROPELLANT REFILL
   - COMPREHENSIVE CHECKOUT
   - REDEPLOYMENT INTO OPERATIONAL ORBIT

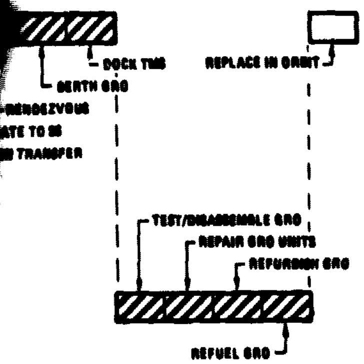
B. MISSION SEQUENCE



D. KEY TDM PRECURSORS

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR
1. TEST/DEMONSTRATION OF ORU REPLACEMENT IN EVA MODE(1)	• UNDER WATER TEST	• ON-ORBIT TEST AND UTILIZATION ON SOLAR-MAX MISSION
2. SATELLITE RETRIEVAL DEMONSTRATION BY CREW MAN USING MMU	• GROUND BASED SIMULATION AND TRAINING, INCLUDING UNDERWATER TESTS	• ON-ORBIT UTILIZATION ON SOLAR MAX MISSION
3. HUD UTILIZATION ON ORBITER-BASED SATELLITE REPAIR MISSIONS(2)	• GROUND-BASED EVALUATION SERIES	• ORBITER-BASED OPERATIONAL USE OF HUD
4. TMS USE IN SATELLITE RETRIEVAL AND REDEPLOYMENT	• GROUND-BASED SIMULATIONS BY TMS MODEL	• ORBITER-BASED OPERATIONAL USE OF TMS
5. FLUID TRANSFER(3)		• OPERATIONAL USE ON GRO REFUELING MISSION

(1)SEE ALSO TDM-2, NO. 1 (2)SEE ALSO TDM-1, NO. 5 (3)SEE ALSO TDM-2, NO. 5



C. MISSION INTERFACES AND SUPPORT REQUIREMENTS

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	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACE:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
BERTHING AREA	●		●	
POWER AND DATA LINES	●			●
FUEL TRANSFER FACILITY	●			●
SUPPORT SERVICES:				
SUPPLY REQUIRED PARTS AND FUEL		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT SERVICING OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
SUPPORT EQUIPMENT:				
SPECIAL ASSEMBLY TOOLS	●		●	
SPECIAL TEST EQUIPMENT	●		●	

(B) STS PRECURSOR	STATUS
ON-ORBIT TEST AND UTILIZA-TION ON SOLAR-MAX MISSION	(B) PROJECTED FOR 1984
ON-ORBIT UTILIZATION ON SOLAR MAX MISSION	(B) PROJECTED FOR 1984
ORBITER-BASED OPERATIONAL USE OF HUD	TBD
ORBITER-BASED OPERATIONAL USE OF TMS	(B) LATE 80s
OPERATIONAL USE ON GRO REFUELING MISSION	(B) ~ 1989

DM-2, NO. 5

E. TDM BENEFITS

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. ORU REPLACEMENT IN EVA MODE	• SAME AS TDM-2, NO. 1
2. SATELLITE RETRIEVAL BY CREWMAN USING MMU	• EXTENDS SATELLITE RETRIEVAL CAPABILITY TO FAILED OR NON-COOPERATING SATELLITES (EXAMPLE - SOLAR MAX MISSION) • INCREASES SATELLITE SERVICING OPTIONS TO WIDER CLASS OF CANDIDATE SATELLITES, AND BACKS UP TMS MODE
3. HUD UTILIZATION	• SAME AS TDM-1, NO. 5 AND TDM-2, NO. 6
4. TMS USE IN SATELLITE RETRIEVAL AND REDEPLOYMENT	• PREREQUISITE TO PERFORMING ROUTINE RETRIEVAL/REDEPLOYMENT IN MOST SATELLITE MAINTENANCE/REPAIR/REFURBISHMENT MISSIONS, ESPECIALLY ON SATELLITES NOT CAPABLE OF PERFORMING REQUIRED MANEUVERING
5. FLUID TRANSFER	• SAME AS TDM-2, NO. 5

OVERALL TDM BENEFIT – EXTENDS LIFE OF SATELLITES, INCREASES UTILITY TO WIDER USER COMMUNITY, ACHIEVES LARGE COST SAVINGS

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Figure 5.2-6. Service/Refurbish Existing Satellite (GRO) (TDM 4)

vicing cycle is considered here. Subsequent repairs to the MPP become necessary. In this event the MPP would be returned to the space station.

Mission sequences (see Figure 5.2-7B) involve activities of the space station, the nearby materials processing platform, and the teleoperator maneuvering system. The space station determines the need for and schedules the servicing mission. The free-flying platform has a largely passive role, generating telemetry except when shut down by command upon approach of the TMS.

The control of this mission is entirely by the space station. It monitors the platform telemetry and commands the TMS. The role of ground facilities is limited except in the case of an anomaly.

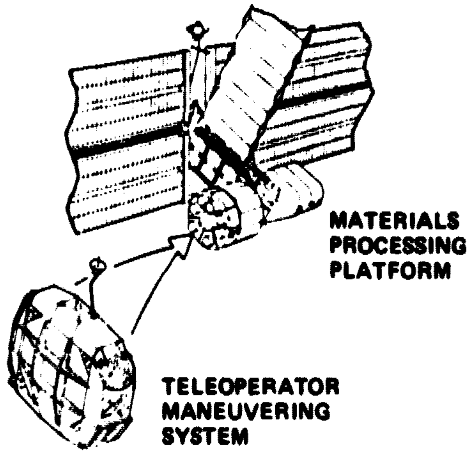
The space station interfaces peculiar to this mission are largely communication interfaces. The physical interface is via the TMS (see Figure 5.2-7C). Extensive specialized support equipment and services will be required for the automated, near-autonomous on-orbit operations.

Precursor activities are listed in Figure 5.2-7D. The anticipated frequent requirement of servicing a free-flying materials processing platform in the space station era, for purposes of resupply of new sample material and return of finished samples, demands a fully mature technology of routine, remotely controlled in-situ operations. Ground-based demonstration and pathfinder tests with various types of materials processing facilities and subsequent on-orbit demonstrations on the shuttle are important stepping stones to developing this technology and gaining confidence in fault-free operational routines.

Although the actual remote servicing techniques will not likely be demonstrated prior to the advent of the space station, we anticipate that some TMS sorties from the shuttle will be flown in the late 1980s as precursors to the automated operations of in-situ module handling. Further study will be required. The timely availability of TMS for early orbital application (prior to 1990) will be a prerequisite to achieving the TD element No. 3. Also, this precursor depends on the state of development of materials processing platforms.

The overall benefit of this TDM is to develop and demonstrate operational procedures that will be essential in future space processing and space industrialization projects and will have to be performed in a routine semi-automatic or fully automatic

A. TDM NO. 5 SUMMARY



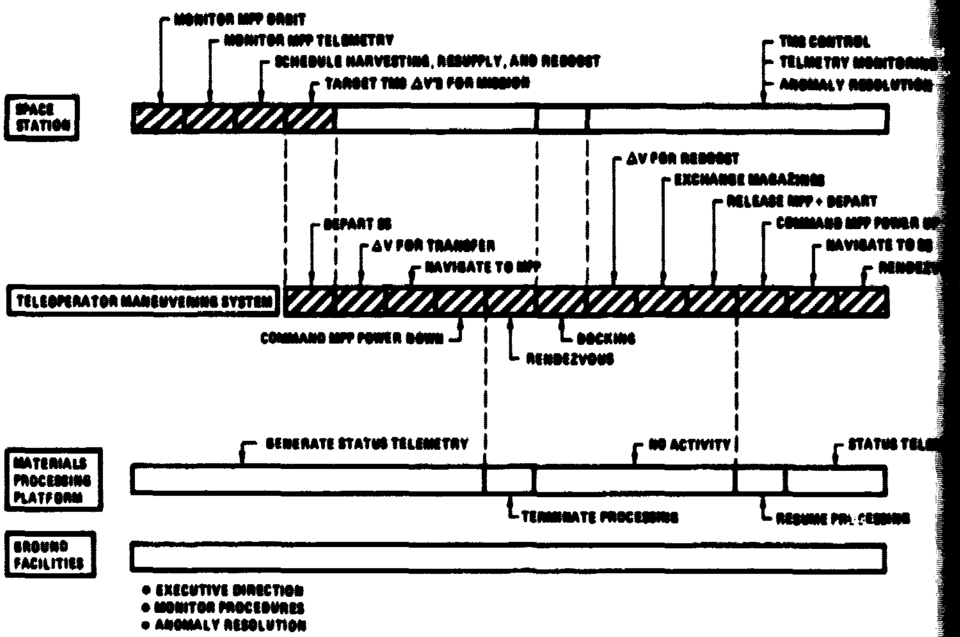
1. TECHNOLOGY DEVELOPMENT AREAS
   - ON ORBIT LOGISTICS CONTROL
   - REMOTE RESUPPLY AND HARVESTING
   - REMOTE REBOOST
   - TMS OPERATIONS

2. BENEFITS
   - ACHIEVE ROUTINE SUPPLY/HARVESTING, ESSENTIAL TO COMMERCIAL SPACE PROCESSING

3. SPACE STATION REQUIREMENTS
   - TMS WITH SERVICE ATTACHMENT OPERATIONAL
   - TV CONTROLLED REMOTE TMS OPERATIONS
   - SPACE PROCESSING PLATFORM DESIGNED FOR REMOTE SERVICING
   - RENDEZVOUS OPERATIONS SCHEDULE MONITORED AND CONTROLLED TO FACILITATE ROUTINE UNMANNED SERVICING SORTIES

4. SCENARIO HIGHLIGHTS
   - TMS DOCKS AT PLATFORM
   - TMS DELIVERS AND EXCHANGES SAMPLE MAGAZINES, RETURNS FINISHED SAMPLES TO SS
   - IN-SITU TMS OPERATIONS CONTROLLED REMOTELY FROM SS VIA TV LINK
   - TMS ALSO PERFORMS ORBIT REBOOST OF PLATFORM ON COMMAND FROM SS

B. MISSION SEQUENCE



D. KEY TDM PRECURSORS

TECHNOLOGY DEVELOPMENT ELEMENT	(A) GROUND PRECURSOR	(B) STS PRECURSOR
1. DEMONSTRATE CHANGE-OUT OF PROCESSING MODULES OR SAMPLE MAGAZINES a) IN HANDS-ON MODE b) IN HANDS-OFF MODE	• PATHFINDER DEMONSTRATIONS ON GROUND • UNDERWATER TESTS	• SHUTTLE-BASED MPS EXPERIMENT SERVICING a) EVA MODE b) RMS OPERATED
2. TMS RETRIEVAL/REDLOYMENT OF FREE-FLYING PROCESSING PLATFORM (PP) FOR SERVICING ON-BOARD SS	(SEE TDM 4, NO. 4	(SEE TDM 4, NO. 4)
3. IN-SITU (OFF-BOARD) PP SERVICING BY TMS BY CHANGEOUT OF a) ENTIRE PROCESS MODULES b) SAMPLE MAGAZINES	• GROUND-BASED DEMONSTRATION AND PATHFINDER TESTS, BOTH (a) AND (b)	• SHUTTLE CONTROLLED IN-SITU PP SERVICING BY TMS (CONCEIVABLE, BUT NOT LIKELY TO BE PERFORMED, DEPENDING ON MPS PROGRAM EVOLUTION) • AUTOMATED TMS RENDEZVOUS ON SHUTTLE IS A DESIRABLE PRECURSOR[1]

[1]SEE ALSO TMS-4, NO. 4

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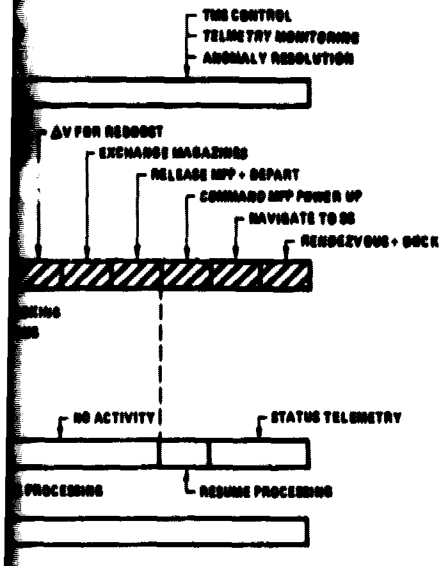

C. MISSION INTERFACES AND SUPPORT REQUIREMENTS

	SPACE STATION	OTHER (NON SS)	MISSION PECULIAR	ASSUMED GENERIC
OPERATIONAL INTERFACES:				
SHUTTLE DOCKING AND CARGO TRANSFER	●			●
VIDEO AND VOICE COMMUNICATION WITH GROUND FACILITIES	●			●
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO MPP	●		●	
RECEIVE TELEMETRY FROM AND ISSUE COMMANDS TO TMS	●			●
PHYSICAL INTERFACE:				
SHUTTLE/SPACE STATION DOCKING FACILITY	●			●
CARGO TRANSFER FACILITIES	●			●
COMMUNICATIONS LINKS TO GROUND FACILITIES	●			●
COMMAND/TELEMETRY LINK FROM SPACE STATION TO MPP	●		●	
COMMAND/TELEMETRY LINK FROM SPACE STATION TO TMS	●			●
TMS/MPP MAGAZINE EXCHANGE SYSTEM	●		●	
SUPPORT SERVICES:				
DESIGN AND MANUFACTURE MPP AND SUPPORT EQUIPMENT		●	●	
CREATE DETAILED PROCEDURES FOR ON-ORBIT MPP SERVICING OPERATIONS		●	●	
MONITOR ON-ORBIT OPERATIONS AND RESOLVE ANOMALIES		●		●
GROUND FACILITIES PROVIDE RAW MATERIALS AND ACCEPT FINISHED PRODUCT		●	●	
SUPPORT EQUIPMENT:				
SPECIAL PACKING CONTAINERS		●	●	
SPECIAL ASSEMBLY TOOLS	●		●	
MPP MONITORING SET	●		●	
MISSION PECULIAR GROUND FACILITY SOFTWARE AND PROCEDURES		●	●	
TMS	●			●
TMS COMMAND SET	●			●
TMS AUTOMATED MAGAZINE EXCHANGE SYSTEM	●		●	

(B) STS PRECURSOR	STATUS
• SHUTTLE-BASED MPS EXPERIMENT SERVICING a) EVA MODE b) RMS OPERATED	(B) LATE 80s
(SEE TDM 4, NO. 4)	(B) LATE 80s
• SHUTTLE CONTROLLED IN-SITU PP SERVICING BY TMS (CONCEIVABLE, BUT NOT LIKELY TO BE PERFORMED, DEPENDING ON MPS PROGRAM EVOLUTION)	(B) TBD
• AUTOMATED TMS RENDEZVOUS ON SHUTTLE IS A DESIRABLE PRECURSOR(1)	(B) TBD

E. KEY TDM BENEFITS

TECHNOLOGY DEVELOPMENT ELEMENT	MISSION BENEFIT(S)
1. DEMONSTRATE CHANGEOUT OF PROCESSING MODULES OR SAMPLE MAGAZINES a. IN HANDS-ON MODE b. IN HANDS-OFF MODE	• ESTABLISHES ROUTINE OPERATING PROCEDURES FOR MODULE AND SAMPLE CHANGEOUT, ADVANCING FROM HANDS-ON TO HANDS-OFF MODES. INITIALLY WITH EVA CREW MEMBER STANDING BY IN HANDS-OFF MODE (RMS UTILIZATION)
2. TMS RETRIEVEAL/REDEPLOYMENT OF FREE-FLYING PROCESSING PLATFORM (PP) FOR SERVICING ON-BOARD SS	• DEMONSTRATES TMS USE IN PP TRANSFER (SEE TDM 4, NO. 4) • DEMONSTRATES/ESTABLISHES ROUTINE ON-BOARD PP-SERVICING
3. IN-SITU (OFF-BOARD) PP SERVICING BY TMS BY CHANGE-OUT OF a. ENTIRE PROCESS MODULES b. SAMPLE MAGAZINES	• DEMONSTRATES IN-SITU PP SERVICING BY TMS FOR FUTURE USE ON OPERATIONAL MISSION; MINIMIZES INTERRUPTION OF PP PRODUCTION CYCLES • DEMONSTRATES MISSION PROFILE SEQUENCE OF PERIODIC PP ORBIT REBOOST OPERATIONS BY TMS (LIVINGSTON SEQUENCE, JSC) ALONG WITH SAMPLE CHANGEOUT

OVERALL TDM BENEFIT – DEVELOPS AND DEMONSTRATES OPERATIONAL PROCEDURES ESSENTIAL TO ROUTINE REMOTE (IN-SITU) MPS PLATFORM SERVICING BY TMS

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Figure 5.2-7. Servicing of Free-Flying Materials Processing Platform (TDM 5)

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mode, under remote control from the space station, see Figure 5.2-7E. In order to make space processing practical and economically attractive, the planned periodic and routine resupply of raw material and harvesting of finished products must be carried out frequently and without malfunction.

Utilization of the TMS is a critical element in this chain of activities. The space station will provide the appropriate operational base for practicing TMS deployment, remote control and retrieval. A simulated or realistic free-flying materials processing platform will serve as the object of validating this technology and debugging the newly developed procedures and support equipment.

5.2.8 Summary of TDM Precursor Activities

Figure 5.2-8 summarizes TDM-related precursor activities to be undertaken prior to the space station involvement. These activities are classified into ground tests, with and without use of a neutral buoyancy facility, and activities conducted on or by the shuttle orbiter. In the latter category, Project COPE ("Capabilities for Opportunities, Payloads and Experiments") is referred to as an example providing low-cost opportunities for exercising selected TDM-related functions on shuttle flights. Crew involvement in checking out the feasibility, practicality, safety or effectiveness of certain TDM operations and hardware design approaches is an important aspect of most of the pre-SS tests and experiments listed in this chart.

5.2.9 Crew Utilization and Crew Safety Concerns

Figure 5.2-9 summarizes the essential role of the space station crew in performing satellite servicing functions. Listed are the unique capabilities of the human operator and resulting key benefits accruing from human involvement, especially where judgement and decision making is required. Functional diversity, adaptability, flexibility, improvisation, visual perception, and response to unforeseen contingencies and failure modes are attributes of the human operator that will be required in most servicing tasks. Substitution of automated/robotic systems would be complex and potentially more costly.

An analysis of space station crew size requirements was performed during TRWs concurrent Space Station Needs, Attributes and Architectural Options Study for NASA Headquarters*.

*TRW Document Z232.83-014, 8 Feb 83
H.L. Harkleroad

SELECTED TDM	GROUND TESTS	NEUTRAL BUOYANCY FACILITY	SHUTTLE (EXAMPLE: PROJECT CAPE)
1. SPACE STATION BUILD-UP BY MANIPULATOR INSTALLATION	• KINEMATIC TESTS WITH SCALE MODELS • INTERFERENCE ENVELOPES • SYSTEM EVALUATION TESTS	• MANEUVERING TESTS • CREW INTERACTION WITH RMS • ASSEMBLY METHODS	• OPERATOR CONTROL TESTS • LOAD CAPACILITY, CONSTRAINTS • ENVIRONMENTAL TESTS • TESTS ON UNIQUE MATERIALS
2. SATELLITE ASSEMBLY AND TEST	• ACCESS TO CRITICAL EQUIP • INTEGRATION PROCEDURES • SATELLITE FUELING TECHNIQUES • AUTOMATION TECHNIQUES	• INTEGRATION TIME LINES • CREW SKILLS, PRODUCTIVITY • DEVELOPMENT OF ASSEMBLY TOOLS, SUPPORT EQUIPMENT	• BUILD-UP OF CRITICAL PARTS • APPENDAGE DEPLOYMENT • ENVIRONMENTAL TESTS ON SELECTED SUBSYSTEMS, PARTS
3. LARGE ANTENNA CONSTRUCTION AND TEST	• ENVIRONMENTAL TESTS OF CRITICAL ANTENNA PARTS • INTERFERENCE TESTING • DEVELOPMENT OF UNIQUE STRUCTURES	• FIDELITY OF KEY ELECTRICAL/MECHANICAL INTERFACES • DETERMINE ROLE OF THE CREW	• MAJOR EVENTS SEQUENCED IN MOST EFFECTIVE FLOW • DEPLOYMENT TESTS OF UNIQUE STRUCTURES, MATERIALS • ANTENNA SYSTEM TESTS
4. SERVICING A FACILITY TYPE SATELLITE	• DEVELOP CALIBRATION, ALIGNMENT PROCEDURES • DEVELOP INTERFACE HARDWARE	• CREW SKILLS, TIMELINES • ASSESS CREW PERFORMANCE AND HAZARDS • DEPLOYMENT TESTS	• WORK OUT CONTINGENCY PLANS • DEMONSTRATE AUTOMATED RENDEZVOUS AND DOCKING ON SIMULATED SPACECRAFT • DEMONSTRATE UNIQUE SERVICING SUPPORT EQUIPMENT
5. SERVICING A MATERIALS PROCESSING FREE-FLYING PLATFORM	• WORK OUT END-TO-END PROCEDURES ON MOCK-MPS • MODELING OF TMS/MPS OPERATIONAL SEQUENCE	• PRIORITIZE CHANGEOUT EQUIPMENT NEEDS • CREW SKILLS, TIMELINES • MAX SIZE EQUIPMENT CAN BE FOR SERVICING	• DEMONSTRATE USE OF RMS AND MMU IN MPS PAYLOAD AND SAMPLE CHANGEOUT • DETERMINE MPS EQUIPMENT LOCATION

Figure 5.2-8. TDM-Related Activities Preceding Space Station

MAN WILL:	RESULTING BENEFIT:
• SENSE UNPREDICTED PROBLEMS AND MAKE REAL-TIME DECISIONS ON THE SPOT	• AVOID UNANTICIPATED COSTLY FAILURES • JUDGE WHEN DATA GATHERING VIA SENSORS IS APPROPRIATE, HENCE REDUCE DATA TRANSMITTED TO EARTH
• PERFORM COMPLEX ASSEMBLY, INTEGRATION AND TEST OPERATIONS	• UNPACK, ASSEMBLE, CHECKOUT DELICATE INSTRUMENTS – LESS RUGGED INSTRUMENT DESIGNS POSSIBLE – COMPLEX MECHANISMS FOR CALIBRATION AND OPERATION UNNECESSARY • WITH HELP OF MANIPULATORS (E.G., RMS) ASSEMBLE OBJECTS TOO LARGE TO BE LAUNCHED INTACT • DEVELOP ON-ORBIT ASSEMBLY FACILITIES, HENCE REDUCE SATELLITE WEIGHT/COST
• SERVICE/MAINTAIN/REPAIR/REPLACE COMPONENTS OR MODULES	• EXTEND LIFE OF SPACECRAFT. IMPROVED PERFORMANCE THROUGH INSTALLATION OF NEWER TECHNOLOGY, REBIRTH OF FAILED SPACECRAFT AND/OR PAYLOADS
• BRING WORLD TECHNOLOGICAL KNOWLEDGE TO BEAR ON EACH SPACE PROBLEM VIA FLEXIBLE DIAGNOSTICS AND COMMUNCIATION WITH GROUND	• REPAIR OF FAILED SPACECRAFT WHERE THERE IS AN UNKNOWN CAUSE OF FAILURE
• UTILIZE VISUAL FEEDBACK TO CONTROL MOVEMENT OF OBJECTS	• SPACE DOCKING/BERTHING; LARGE STRUCTURE ASSEMBLY
• REDUCE ON-BOARD AUTOMATIC COMPLEXITY AND REDUNDANCY	• LOWER HARDWARE AND SOFTWARE COSTS

Figure 5.2-9. Man's Attributes Will Enhance On-Orbit Satellite Servicing

It showed that a growth from 5 to 10 crew members will occur in the course of space station evolution in the 1990s. Thus the assignment of at least two or three men to tasks required for servicing TDMs can be accommodated comfortably.

Crew safety is an overriding concern in defining, planning and implementing TDMs such as the sample missions investigated in this study as well as shuttle based precursor missions.

Actually, none of the tasks we have identified constitute an inerently greater safety hazard than other EVA operations projected for future shuttle or space station missions. However, in utilizing novel crew support equipment such as the manned maneuvering unit (MMU), the RMS cherry picker, new payload handling and positioning equipment and/or multiple RMS support, special care must be exercised to provide adequate training and to perform in flight missions with all necessary safety precautions.

5.2.10 Space Station Resources and Capabilities Utilized by TDMs

Figure 5.2-10 presents a breakdown of space station resources, attributes and capabilities involved in, or required for the servicing activities that are to be performed in each of the five selected example TDMs. Dark circles indicate major dependence, open circles moderate dependence (or interaction) of these TDM activities on (or with) SS resources and features.

The purpose of the chart is to exhibit the degree by which each of the TDMs interact with the SS, as a further check on the suitability of our TDM selection. A high degree of TDM dependence/interaction in most of the SS capability columns indicates a comparatively high level of mission complexity (and vice versa) and also tends to justify the selection in terms of the multiple SS capabilities and functions that will be exercised by that mission.

5.3 TECHNOLOGY DEVELOPMENT MISSION PROGRAMMATIC ANALYSIS

This task of the study produced as principal outputs a schedule and cost estimate for each of the five TDMs. In addition, for each TDM, three other tasks were completed. A critical item/risk assessment was made as was a study comparing conduct of the mission using the early space station versus using the shuttle. The potential impact of the TDMs on the environment was investigated. Costs varied widely for the TDMs and two alternative approaches were scheduled and costed for three

TDM CATEGORY	SELECTED EXAMPLE TDM / MSS RESOURCES ATTRIBUTES AND CAPABILITIES	STABLE CONSTRUCTION AND OPERATION PLATFORM	PERMANENT PRESENCE	LOGISTICS AND SUPPLY BASE (FOCUSES STS TRAFFIC)	LARGE STORAGE DEPOT (INCL PROPELLANTS)	EXPANDED CREW SIZE, LONG-DURATION HABITAT	INCREASED POWER CAPACITY	LARGE COMPUTER AND DATA MGT CAPACITY	TEST FACILITY AND SUPPORT EQUIPMENT	PROVIDES COORBITING SPACE PLATFORM FACILITIES	TMS/OTV OPERATIONS BASE
I	1. SS - BUILDUP BY MANIPULATOR INSTALLATION*	●	●	●	●	●	○	○	○		
II	2. SATELLITE ASSEMBLY, TEST AND LAUNCH	●	○	●	●	●	○	●	●		○
II	3. LARGE ANTENNA CONSTRUCTION AND TEST	●	○	○	○	●	○	●	●	○	
III	4. SERVICING GRO SPACECRAFT	○	●	○	●	●	○	●	●		●
III	5. SERVICING MATERIALS PROCESSING PLATFORM	○	●	●	●	○		○		●	●

LEGEND
- * IN THIS TDM THE SPACE STATION IS ALSO THE PRIME OBJECT OF SERVICING ACTIVITY
- ● MAJOR DEPENDENCE } ON MSS CAPABILITIES/RESOURCES
- ○ MODERATE DEPENDENCE } ON MSS CAPABILITIES/RESOURCES

Figure 5.2-10. Space Station Role in TDM Mission Implementation

TDMs to provide information about the possible range of costs. Figure 5.3-1 shows the basic cost and scheduling assumptions for each of the TDMs including the alternatives for TDMs 2, 3 and 5.

Schedule. Figure 5.3-2A is a composite schedule for the five TDMs detailed by TRW. TDMs 2, 4 and 5 can occur in approximately the same timeframe - in 1991 shortly after the early space station becomes operational. TDM 4 involving GRO has the most critical schedule since its mission by current schedules is completed in the second quarter of calendar 1990 - about six months before IOC of an initial space station. TDM 1 depends upon the growth cycle planned for the space station and TRW's space station study tentatively shows growth to incorporate a mobile manipulator capability occurring in 1983. TDM 3 is dependent upon large structure and large antenna technologies and the projected need for that technology.

This composite schedule also gives some feel for the relative lead time required for the TDMs. TDM 4 requires the least lead time; since it utilizes GRO, a funded and planned program. TDM 3 requires the longest, again, for technology reasons.

Cost. Figure 5.3-2B shows the costs for each proposed TDM including alternative approaches for TDMs

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TDM	CHARACTERISTICS/ASSUMPTIONS
1 BUILDUP OF SPACE STATION MANIPULATOR CAPABILITY	• TDM IS AN ADDITIONAL TASK TO SPACE STATION MOBILE MANIPULATOR CONSTRUCTION • MINIMUM LEVEL OF NEW HARDWARE AND SERVICE REQUIRED
2 ON-ORBIT ASSEMBLY, TEST AND LAUNCH OF SPACECRAFT	APPROACH 1 • AN EXPERIMENTAL SPACECRAFT IS BUILT FOR TDM • USE EXISTING SUBSYSTEM DESIGNS • REDUCED REDUNDANCY REQUIREMENTS
	APPROACH 2 • ASSUME AN EXISTING SPACECRAFT PROGRAM SATISFIES TDM NEEDS • TDM IS AN ADDITIONAL TASK IN THE DEPLOYMENT OF THE SPACECRAFT
3 LARGE ANTENNA STRUCTURE DEPLOYMENT	APPROACH 1 • AN EXPERIMENTAL 60 METER ANTENNA IS BUILT FOR TDM
	APPROACH 2 • ASSUME AN EXISTING PROGRAM IS BUILDING A 60 METER ANTENNA FOR SPACE DEPLOYMENT • TDM IS AN ADDITIONAL TASK IN ANTENNA DEPLOYMENT
4 SERVICE/REFURBISH SATELLITE (GRO)	• TDM USES GRO AT END OF ITS MISSION • MINIMUM LEVEL OF NEW HARDWARE AND SERVICE REQUIRED
5 SERVICING FREE FLYING MATERIALS PROCESSING PLATFORMS (MPP)	APPROACH 1 • TDM USES EXISTING MPPs. MINIMUM NEW HDWRE/SERVICES
	APPROACH 2 • EXISTING MPPs USED. SOME NEW SS AND TMS AUGMENTATION

Figure 5.3-1. Summary of Cost/Schedule Assumptions

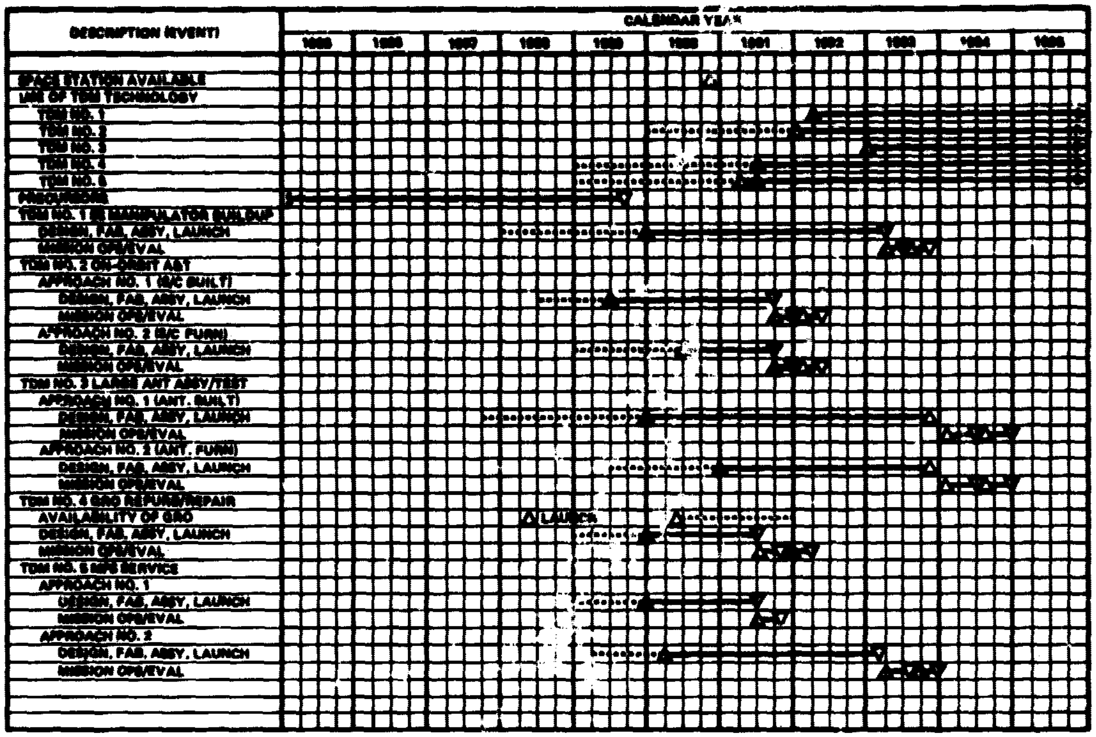
2, 3 and 5. The costs for TDMs 1, 4 and 5 are modest relative to 2 and 3 and are characterized by the use of existing systems. Costs for these TDMs are relatively minimal since very little in the way of new hardware and services are required. The largest TDM cost occurs for Approach 1 of TDM 2, where a 60 meter antenna is constructed. If a large antenna is already available for TDM 3, then the cost is lower. This lower cost is still significantly larger than TDMs 1, 4 and 5 since the TDM is still relatively complex.

TDM 1 involves the technology of space construction related to activities in the placement of a track for a mobile manipulator arm on the space station. Since this TDM mainly involves observation and evaluation of the construction activity, little in the way of significant additional hardware needs to be developed.

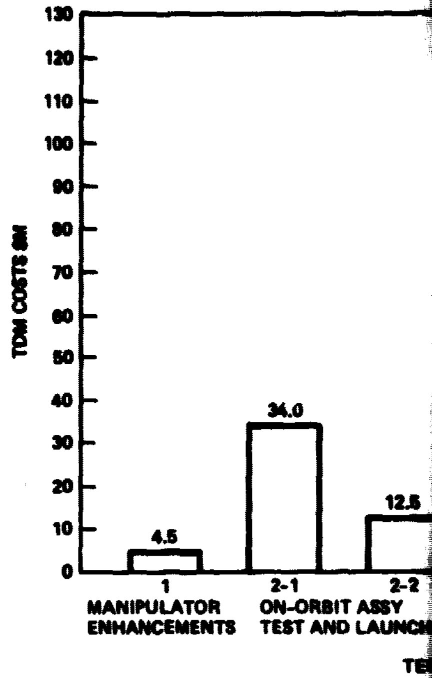
For TDM 2, two cost estimates were provided. Approach 1 assumes that an experimental spacecraft is built as part of the TDM while Approach 2 assumes that an existing space program has a spacecraft that can justify the needs of the TDM.

For TDM 3, two approaches to cost estimates were also taken. In Approach 1, a 60 meter antenna with associated feeds, sensors and test

A. SUMMARY SCHEDULE FOR FIVE TDMs



B. COST FOR EACH OF FIVE TD



D. SUMMARY – TDM CRITICAL ITEM AND RISK ASSESSMENT

CRITICAL ITEM	TDM 1	TDM 2	TDM 3	TDM 4	TDM 5	COMMENT
1. STS DELAY	○	○	○	○	○	PRIMARILY COST/SCHEDULE RISKS
2. TIME TO PERFORM TDM ON-ORBIT	◑	◑	◑	◑	◑	MODERATE RISK – ALL TDMs
3. SPACE STATION AVAILABILITY/CAPABILITY	○	◑	◑	◑	◑	
4. TMS AVAILABILITY	-	-	◑	◑	◑	UNAVAILABILITY CURTAILS OBJECTIVES – PARTICULARLY TDM-5
5. TDM EQUIPMENT DESIGN	○	◑	●	○	○	PRIMARILY COST/SCHEDULE RISKS
6. TRACK SYSTEM AVAILABLE	◑	-	-	-	-	
7. SIMULATED SPACECRAFT ADEQUATE	-	◑	-	-	-	
8. TECHNOLOGY AVAILABLE	◑	○	●	○	◑	TDM NO. 3 DEPENDS HEAVILY ON PRECURSOR TECHNOLOGIES

○ LOW RISK ◑ MODERATE RISK ● HIGH RISK

E. SUMMARY – COMPARISON

DESCRIPTION
COMMON – ALL TDMs
TIME ON-ORBIT
STS TRANSPORTATION COSTS
STORAGE
RETURN EXPERIMENT TO GROUND
UNIQUE
ANTENNA SIZE (TDM-3)
GRO END OF LIFE (TDM-4)
FLEXIBILITY OF HARVESTING/ REPLENISHMENT SCHEDULES (TDM-5)
SPACE ENVIRONMENT (TDM-2)

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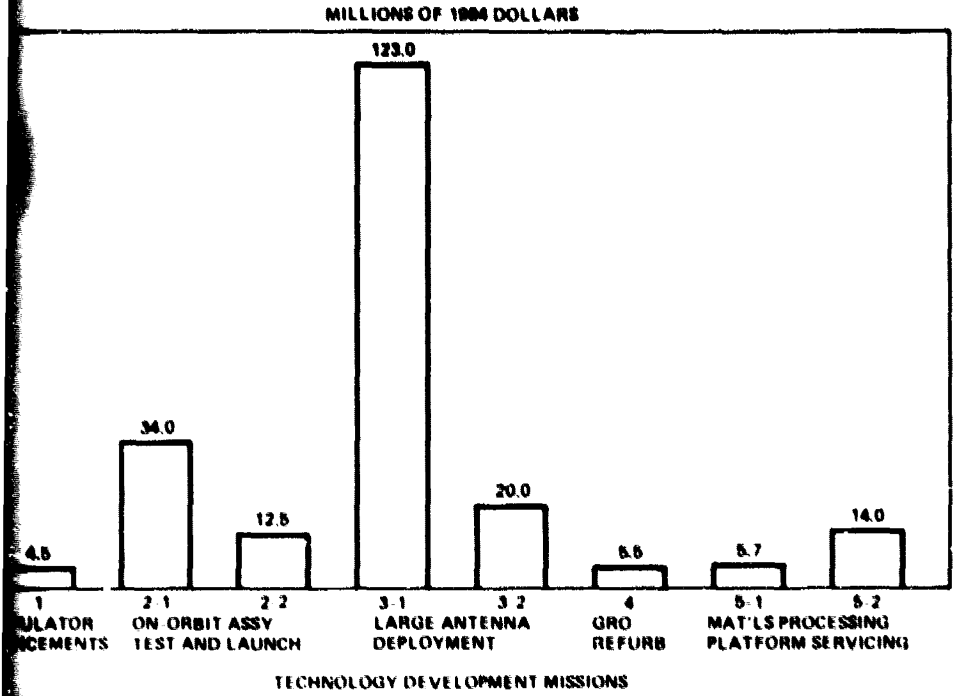
OR EACH OF FIVE TDMs



ARY – COMPARISON – EARLY SPACE STATION VS SHUTTLE

DESCRIPTION	ADVANTAGE		COMMENT
	STS	SS	
ALL TDMs			
ORBIT		✓	STS NOT TIED UP FOR TEST. MORE NONCONTIGUOUS TEST TIME AVAILABLE
NSPORTATION COSTS		✓	MINIMIZED WITH OPTIMUM MANIFESTING. SUPPORT EQUIPMENT FOR CONTINUING USE LEFT IN PLACE
E		✓	FLEXIBILITY IN STORING PARTS
EXPERIMENT TO GROUND	✓		QUICKEST TURN AROUND FOR GROUND REWORK
A SIZE (TDM 3)		✓	CAN BE LARGER THAN ON STS. CAN BE SALVAGED COMPARED TO GEO
OF LIFE (TDM 4)	✓		GRO MAY REQUIRE DEORBITING BEFORE SPACE STATION IS READY
LITY OF HARVESTING RHMENT SCHEDULES		✓	SPACE STATION SUITED AS WAY STATION FOR OPTIMUM PRODUCTION OF MATERIALS IN SPACE
NVIRONMENT (TDM 2)		✓	ACTUAL TEST IN SPACE ENVIRONMENT FEASIBLE

C. SPACE STATION CREW REQUIREMENTS

TDM	EVA HOURS	IVA HOURS	TOTAL HOURS
1 BUILDUP SPACE STATION MANIPULATOR CAPABILITY	40	40	80
2 ON ORBIT ASSEMBLY TEST LAUNCH	100	100	200
3 LARGE ANTENNA DEPLOYMENT	140	200	340
4 SATELLITE REFURBISHMENT (GRO)	40	40	80
5 MATERIALS PROCESSING PLATFORM SERVICING	0	100	100

NOTE: THESE ARE BASIC TASK TIME ESTIMATES WITHOUT FACTORS FOR EFFICIENCY, PREPARATION, ETC.

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Figure 5.3-2. Programmatics

electronics is built. For Approach 2, a large antenna that satisfies TDM 3 objectives is assumed to be available from an existing program and the TDM is assumed to be an additional task added to the antenna deployment on the space station.

TDM 4 uses the existing GRO system so this TDM will also require very little in the way of new hardware development.

Similarly TDM 5 has two approaches. Approach 1 assumes the TDM uses existing materials processing platforms to perform the mission. Approach 2 has more capability added as part of the TDM for more complex, automated servicing of the free flying platform with comparable capability at the space station.

The following ground rules and assumptions characterize the cost estimates of all proposed TDMs. All cost estimates are in 1984 dollars and exclude contractor fees. All TDMs will require space station support in terms of equipment and crew time and this support is assumed to be available at no cost to the TDM. (Figure 5.3-2C shows the estimate of crew time for each TDM.) Similarly STS costs are not included in these estimates and the NASA test facilities are assumed available at no cost to the TDM.

The costing methodology is based upon the use of TRW cost estimating relationships (CERs), the RCA PRICE program, analogy with past TRW experience and estimating labor hours for a specific task or level of effort.

Critical Item and Risk Assessment. The key critical items and a qualitative assessment of the risk is shown in Figure 5.3-2D. The highest risk centers around TDM 3 "Large Antenna Structure Deployment" where new technology, as yet unproven in a space environment, is involved. Achieving both the required technology and the hardware for an on-orbit experiment involves substantial risk. In absolute terms the risk to the TDM is greatest if the TDM bears the risk of experimental hardware development and manufacture.

Early Space Station vs. STS.

The early space station provides several broad and several specific advantages over the STS for conduct of these TDMs as shown in Figure 5.3-2E. These are some of the same advantages favoring a space station as identified in our space station study for NASA Headquarters.

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6.0 CONCLUDING REMARKS

Space stations, at appropriate orbital inclinations, are needed to advance space-based satellite servicing toward a fuller, more effective and economical utilization of spaceflight, starting with a broadened research and development flight program in the early 1990s for servicing technology enhancement and thrusting to full scale operations by the end of this century.

Results of this Satellite Servicing Technology Development Missions for Early Space Stations study produced these principal conclusions:

1. On-orbit satellite servicing is technically feasible.
2. On-orbit satellite servicing will support a wide range of NASA, DOD, and commercial missions. The broad nature of this support will protend operational, and economical benefits to the users.
3. The early space station can and must play a vital role in developing a national satellite servicing on-orbit capability.
4. Development of certain critical technology elements needed to perform on-orbit satellite servicing should be started at an early date.

In evolving a technology base for future satellite servicing from the space station, many issues and design questions pervade considerations in various disciplines. The degree of autonomy desired and man-machine interface questions are typical examples. In addition, the initial and life-cycle costs and evolutionary growth guidelines are clearly the dominant drivers in planning a technology program responsive to satellite servicing/space station needs. To better describe the technology goals and to facilitate communications across disciplinary lines, this study has <u>identified</u> an initial list of primary TDMs and <u>derived</u> their requirements.

Dominant study results deal with seven items:

1. Satellite servicing technology development missions:
   a) Five system's level TDMs were conceptually defined, planned, and costed. Their space station precursor tests, role of the early space station, and benefits were analyzed. The TDMs combined technology development with operational usefulness.
   b) Twenty-six technology development elements, associated with the five TDMs, were identified.
2. Space station's role in on-orbit satellite servicing highlighted as:
   a) Provide long duration base for TDM implementation.

b) Provide necessary resources for conducting TDM operations.

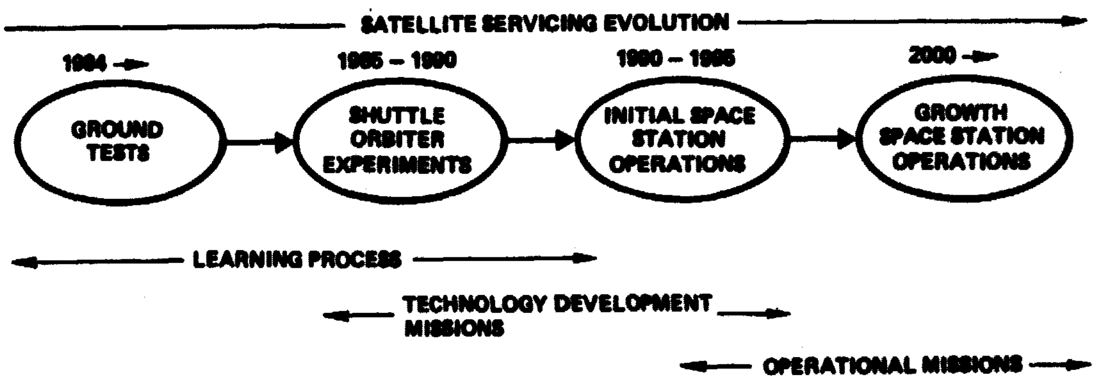
c) Provide laboratory mode for equipment trials, techniques development, establishment of standards, training, and contingency servicing.

d) First step in the evolutionary growth of servicing from development to operational status.

3. Existing technology is insufficient, in some areas, to allow the conduct, at present, of operational on-orbit servicing. The study identified a list of important technologies that must start now.

4. Some current ground-based assembly/test, simulations, and training facilities are relevant to space-based satellite servicing.

5. Satellite servicing will proceed in an evolutionary, rather than a revolutionary manner. It will be closely tied to space station evolution.



6. Benefits of on-orbit satellite servicing. The seven United States and seven international spacecraft manufactures we contacted siad they could see a long term benefit of satellite servicing. Benefits they perceived aiming at extending satellite lifetimes and usefulness, include:

a) On-orbit assembly and test of spacecraft or major, elements of spacecraft.

b) Propellant loading.

c) Test and deployment of deployable equipment and structures.

d) Analysis and troubleshooting primarily by visual observation.

e) Replacing or adding equipment, instruments for mission flexibility and growth.

f) Replenishing of consumables.

g) Cleaning and refurbishing satellite surfaces.

h) Geosynch servicing if costs are in-line with benefits.

7. Role of the space station crew in the conduct of the TDM

a) Evaluate the flight crew during typical satellite servicing operations to help determine the crew's optimum role and to quantify crew productivity.

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b) Provide in-flight data on man/machine interfaces to enhance the efficiency and safety of the crew in future missions.

Seven issues dominate the thinking and planning relative to on-orbit satellite servicing. They are listed below. Some pertain to technology and engineering; most depend on NASA programmatic decisions; they all deserve near-term attention.

The follow-on (Part II) phase of this study, which MSFC plans to initiate in June 1983 and continue for 18 months, will generate further details on the above results, issues, and conclusions.

Finally, it is uncertain at this time if budget reality will allow near term implementation of efforts directed at all of the technology

1. Safety - Crew and mission safety standards will be imposed on satellite servicing operations. In order for satellite servicing to achieve a routine operational status, the operations will have to be proven to be low risk. Safety criteria needs to be developed.

2. Project Costs - Goals for the initial satellite servicing using the early space station will certainly reflect NASA funding constraints.

3. Space Systems Designed for Servicing - For satellites and space systems to be effectively and economically serviced on-orbit, they must be designed for it. Future spacecraft specifications must reflect this operational mode.

4. Space Station Evolution - Architecture and capability and IOC of the early space station and evolutionary path to increased capability will impact satellite servicing progress.

5. Technology Readiness - The pace at which equipment and techniques and crew skills are developed will effect satellite servicing growth.

6. Operations Costs - Transportation, logistical, ground/flight operations and control, training, and equipment replacement costs could dominate the total project.

7. User Acceptance - NASA yes, but will DoD, international and private sector (commercial) users want their space systems serviced on orbit?

goals identified by this study. However, it is reasonable to say that an extremely challenging technology development study phase for satellite servicing has been initiated by NASA. Over the next 18 months (Part II of this study) NASA can be expected, within their priorities and the resources available, to move aggressively ahead toward enabling effective satellite servicing operations to become one or our next logical steps in space.

ACKNOWLEDGEMENT

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E. H. Medler	Donald M. Waltz
Robert E. Orr	Robert E. Wong

APPENDIX A

RELATED DOCUMENTATION

In this study we utilized the results of pertinent recent studies of satellite on-orbit servicing, shuttle and space station operations performed by TRW and other NASA or USAF contractors, as well as NASA and AF in-house generated study reports. A list of applicable documents is given below.

	Study Title	Organization	Date
1.	"In-Space Servicing of DSP"	TRW	1973
2.	"Earth Resources Mission Planning Study"	TRW	1974
3.	"Shuttle/Payload Orbital Operations Study"	TRW	1976
4.	"Science and Applications Space Platform Study"	TRW	1979-1980
5.	"Power Systems Platform Design Study"	TRW	1980-1982
6.	"Materials Experiment Carrier Design Study"	TRW	1981-1982
7.	"Integrated Orbital Servicing Study" (Final Report Vol. I-III)	Martin/Marietta/TRW	1978
8.	"Astrophysics Explorer/MMS Launch/ Retrieval and On-Orbit Servicing Modes"	TRW	1978
9.	"Satellite Services System Analysis Study"	Lockheed	1981
10.	"SOC/Shuttle Interaction Study" (Final Report)	Rockwell	1982
11.	"Utility Analysis of Manned Space Platform for Defense Related Mission (Task C)"	MDAC	1981
12.	"Space Operations Center/System Analysis" (Final Report Vol. I-IV)	Boeing	1981
13.	"SOC System Analysis - Study Extension" (Final Report Vol. I-IV)	Boeing	1982
14.	"Conceptual Design Study/Science and Applications Space Platform" (Vol. I Executive Summary)	MDAC	1981
15.	"Science and Application Space Platform Payload Requirements Accommodation"	TRW	1980
16.	"Alternatives System Design Concept Study 25kW Power System Space Platform Summary"	TRW	1981 (Final Rpt) 1982 (Follow-on)
17.	"Evolutionary Space Platform Concept Study" (Vol. I-III)	MDAC	1982
18.	"Satellite Services System Analysis Study"	Grumman	1977
19.	"Teleoperator Maneuvering System Mission Requirements & System Definition Study" (Vol. I-III)	Vought Corp.	1982 & Subsequent
20.	"Space Industrialization Study"	Science Applications, Inc.	1978
21.	"Satellite Services Workshop" (Vol. I-II)		1982

	Study Title	Organization	Date
22.	"Gamma Ray Observatory Maintainability Studies"	TRW	1981 & Subsequent
23.	"AXAF Utilization of STS and Satellite Servicing Conference	Science Applications, Inc.	
24.	"Space Station Needs, Attributes and Architectural Options Study"	TRW	1983
25.	"Definitions of TDMs for Early Space Station - Large Structures"	Boeing	1983
26.	"Definition of TDMs for Early Space Station - OTV Servicing"	GDA	1983
27.	"Definition of TDMs for Early Space Station - Satellite Servicing	Martin Marietta	1983
28.	"Space Station Ground Operations Study"	MDTSCO	1983
29.	"Space Operations Study"	MDTSCO	1983